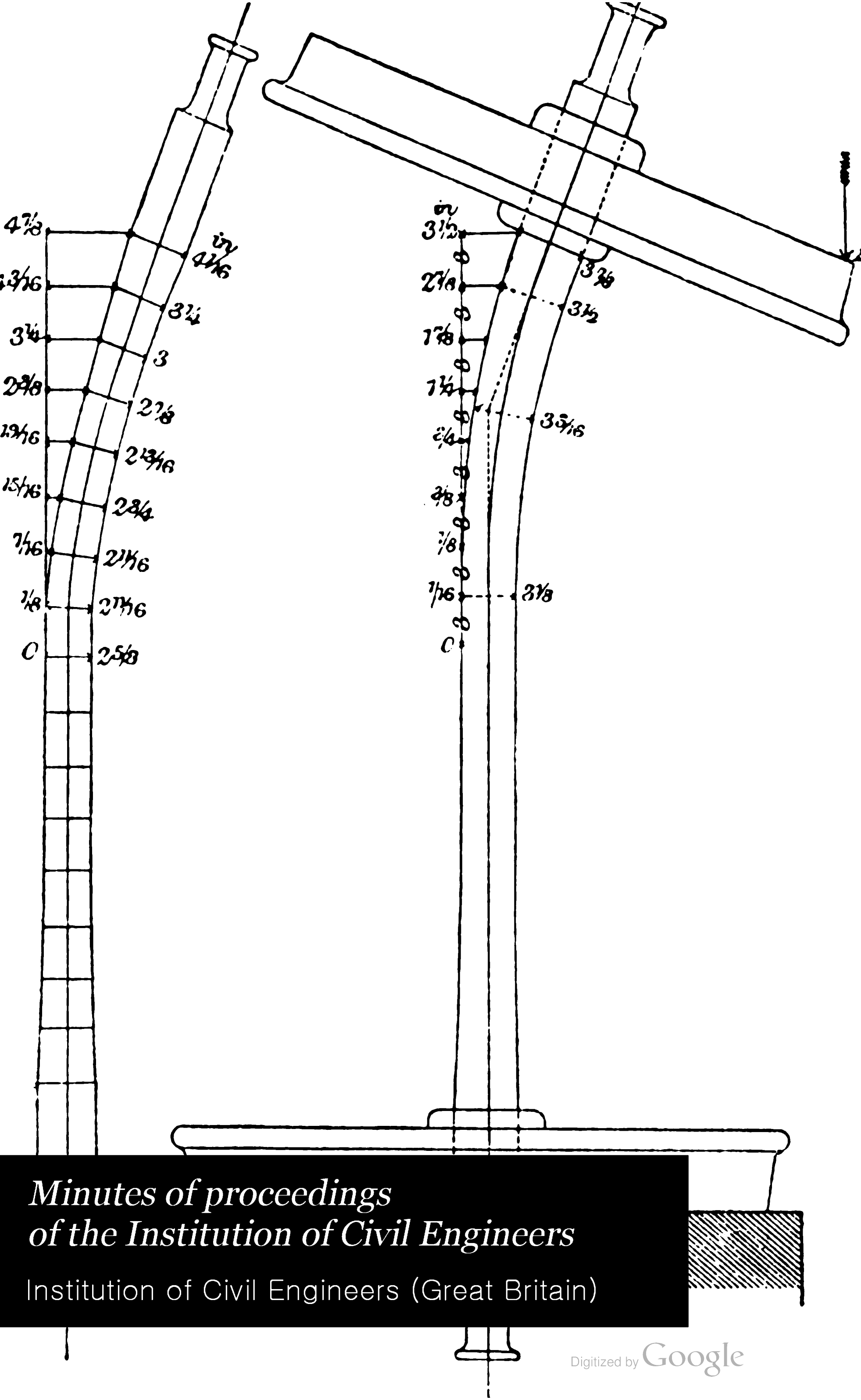

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XLVI.

SESSION 1875-76.—PART IV.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1875-76.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

April 25, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

No. 1,456.—"The Dhu Heartach Lighthouse." By DAVID ALAN STEVENSON, B.Sc. Edin.

THE Commissioners of Northern Lighthouses have recently, after six seasons' work, completed the erection of a lighthouse tower on the Dhu Heartach Rock. With many incidents of difficulties overcome and of dangers met, it has a history very similar to the Edystone, the Bell Rock, and the Skerryvore lighthouses, which, as is well known, have been fully described in the narratives of their respective Engineers.[1] But in drawing up the following notice, the Author has restricted his remarks to a bare record of engineering facts, the materials for which have been derived from the annual reports of Messrs. D. and T. Stevenson, MM. Inst. C.E., to the Commissioners, and also from personal knowledge acquired during periodical visits made while the works were in progress.

Although the necessity for a lighthouse on Dhu Heartach had been frequently brought before the Northern Lighthouse Board, it was not till the year 1867 that the Commissioners found themselves in a position to proceed with the work. The chart (Plate 1) shows the important position occupied by Dhu Heartach with regard to the entrance to the Irish Channel, to the Frith of Clyde, and to the navigation of the Minch. The lighthouse of

[1] *Vide* "Narrative of the Building, and a Description of the Construction of the Edystone Lighthouse, &c.," by J. Smeaton, London, 1871; "An Account of the Bell Rock Lighthouse, &c.," by R. Stevenson, Edinburgh, 1824; and "Account of the Skerryvore Lighthouse, &c.," by A. Stevenson, Edinburgh, 1848.

Skerryvore is 19½ nautical miles to the north-west, and the Rhins of Islay 27 nautical miles to the south, leaving between the two existing lights an intermediate stretch of unlighted coast of 43 miles. Dhu Heartach is 14 nautical miles from the shore station on the Island of Earraid in Mull, the nearest land. A dangerous reef, called the Torrin Rocks, extends from the Ross of Mull for 4½ nautical miles in the direction of Dhu Heartach, which, indeed, may almost be regarded as the outer extremity of the reef, although it is 9 miles beyond the outermost rock. To homeward-bound vessels making the shore, not having sighted either Skerryvore or the Rhins of Islay, no warning whatever announced their approach to this treacherous group of rocks, which have proved destructive to many a ship, the only evidence of the wrecks being the drift timber thrown ashore on the neighbouring coasts of Mull and Iona.

The Dhu Heartach group, according to the survey of Captain E. J. Bedford (Plate 1), consists of the main rock, five detached tide-covered hummocks, and two small sunken rocks. The main rock is an isolated mass of trap, 240 feet in length and 130 feet in breadth, with a rounded top rising to 35 feet above high water of ordinary spring tides. It is surrounded on all sides by deep water, and, excepting between the bearings W. ½ N. to N.W., none of the outlying rocks of the group afford the main rock any shelter. Even very slight swells from the west, after breaking on its western face, divide and sweep round the north and south ends of the rock, as separate waves, meeting together at the eastern side, and leave no spot round its margin to which a boat can, even with a moderate westerly swell, safely approach; while the depth of water close to the rock, and the form of the bottom to the west, admit of waves of great size and power being thrown upon it during heavy storms.

An important matter, connected with the establishment of a light in such a locality, is the selection of a suitable site on shore, as a basis for conducting the works, and for the erection of houses for the lightkeepers and crew of the attending vessel, who are permanently in charge of the lighthouse. After a careful examination of the adjoining coast, Earraid, at the western extremity of the Island of Mull, was fixed on as the most suitable spot for the shore station. Though 14 miles distant from the rock, it was the nearest place with which communication could be kept up, and presented the advantage of affording an abundant supply of excellent granite; and there, accordingly, the ground for the permanent dwellings of the lightkeepers and seamen, as well as for quarries, workyards,

stores, &c., was acquired by the Commissioners from the proprietor, his Grace the Duke of Argyll, who afforded every facility that could be desired. There also a wharf was erected for shipping the materials, no dock or harbour works being required, as the Sound of Earraid is tolerably sheltered.

As regards the form of the tower, Messrs. Stevenson, after trying various curves, fixed on the parabola as best suited to the required conditions, and the lighthouse tower is a parabolic frustum surmounted by a plain cavetto, abacus, and parapet, the upper course of which is 107½ feet above the foundation (Plate 2). It was considered that the lines of the parabolic shaft, running without break into those of the cavetto, would produce a better architectural effect, in a tower of the height proposed for Dhu Heartach, than could have been obtained by the introduction of a belt course, so successfully used in higher towers. Besides, on engineering grounds, it was deemed inadvisable in this particular case to oppose a belt course to the seas which might be projected up the face of the tower. The maximum diameter of the Dhu Heartach tower at the base is 36 feet, and the minimum at the top is 16 feet. The doorway is 32 feet above the foundation, and the interior is divided into six compartments, or rooms, affording accommodation amounting to 5,500 cubic feet. The total weight of the tower is 3,115 tons, of which 1,840 tons are contained in the solid base. The excellent grey granite, of which the tower is constructed, was quarried in the immediate neighbourhood of the shore station.

Having made these general statements, the Author has now to offer the following brief outline of the progress of the works during each of the six years occupied in their construction, noticing, at the same time, such engineering facts as may, it is believed, prove interesting.

1867.

The authority to begin the works was only obtained on the 11th of March, 1867, so that little more than preparation could be done during that season. In the expectation that the landings on the rock would prove peculiarly difficult and uncertain, and that water and provisions might often be got upon the rock, although not possible to land workmen, it had been resolved to erect, as at the Bell Rock and at Skerryvore, a barrack for the workmen, so that the work on the rock might be prosecuted at times when the sea was too high to admit of landing. It was also considered a source of safety in case of the workmen not being able to get off the rock from a sudden rising of the sea. The construction of this barrack,

hereafter referred to, was obviously a part of the work with which no time should be lost. A powerful steam-tug was therefore chartered, and twenty-seven landings were made between the 25th of June and the 3rd of September, after which no landing could be effected. But, short as the season's work was, the men did good service in beginning the excavation for the foundation of the tower, and in erecting the first tier of the barrack, which was left to encounter the winter's gales. The winter of 1867 was occupied in building the steamer "Dhu Heartach," to be employed chiefly in towing the stone lighters and other service, and in constructing lighters, cranes, and plant generally, so as to be in readiness for the next season's work.

1868.

The attending steamer arrived at Earraid on the 14th of April, to take advantage, as was anticipated, of the easterly winds, which generally prevail during the spring months. But strong westerly winds continued almost without intermission till the end of June, during which period of two and a half months no work was done upon the rock. Various attempts were from time to time made to land, but without success, except on the 4th of May, and even then the men could only remain one hour and a half; but time was afforded to ascertain that the work of the last season had stood on the whole well, considering its unfinished state. One section of the iron ring connecting the heads of the uprights of the first tier of the barrack, at a height of 30 feet above high-water level of spring tides, had, however, been carried away. Again on the 18th of May six men landed, it being unsafe to land a greater number, but the sea continuing to rise, they were taken off after being about one hour and a half on the rock. The weather then became more unfavourable, and no landing was made till the 29th of June. The wind, indeed, never fairly settled into the east, so that more or less of a westerly swell continued throughout the whole season, being the most unfavourable weather for the progress of the work. The following is the number of days in each month that a landing on the rock was practicable:—May, two days; June, two days; July, thirteen days; August, ten days; and September, eleven days; together thirty-eight days.

The progress, however, was encouraging; the barrack for the workmen was completed on the 28th of September, and about three-fourths of the foundation of the tower was excavated.

The barrack (Plate 1) consisted of a malleable iron framing rising to a height of 35 feet above the rock. This framing con-

sisted of four tiers; the uprights of the lowest tier, twelve in number, were sunk 3 feet into the rock, and were lewised and run in with cement. They measured 4 inches square, the sectional area of the succeeding tiers being gradually reduced to 2 inches square at the top. On this framework, which was strongly bound together with internal stays and ties, was fixed the habitable part of the barrack, formed of a malleable iron drum of riveted plates, $\frac{1}{4}$ inch thick, 18 feet 9 inches in height, and 16 feet in diameter, divided into two storeys for the accommodation of the workmen. On account of the great exposure of the structure, malleable iron was chosen as a more suitable material for the framework of the barrack than wood, which had been employed for a similar purpose at the Bell Rock and at Skerryvore. It was fortunate that this precaution was adopted, as there can be little doubt, from the way in which the barrack was struck by heavy seas, that a framework of timber would not have stood in that situation. It was not, indeed, intended that the barrack should be inhabited till its stability had been fully tested by a winter's storm. But in order to hasten its completion before the end of the season, Mr. Alan Brebner, of Messrs. Stevenson's firm, who had gone out specially to inspect the works, remained with thirteen workmen on the barrack on the evening of the 20th of August, in the expectation that the fine weather then prevailing would admit of the work being carried on continuously, without the interruptions occasioned by going ashore to Earraid, to which place the steamer went for anchorage in the evening. A sudden gale sprang up, however, during the night, rendering it impossible to land on the 21st, and the occupants of the barrack could not be communicated with till the 26th, being closely imprisoned within the drum. During the height of this five days' storm, heavy broken water frequently rose far above the barrack, and falling on the top, which was 77 feet above high-water level, completely excluded all light for several seconds. The sea also struck so heavily on the flooring of the lower compartment that it burst up the hatch, which was 35 feet above the rock, and about 55 feet above high-water level. The Author is particular in mentioning this, for, as will afterwards be stated, the observation of the sea on this occasion had, along with subsequent experiences, the effect of inducing a change in the original design of the tower.

The works on shore at Earraid were vigorously carried on; the quarries were fully opened out, a considerable portion of the stones for the foundation course of the tower were dressed, the landing-place was improved, and the dwelling-houses were far advanced.

1869.

On the 22nd of March the "Dhu Heartach" steamer arrived at Earraid. The first landing was effected on the 25th of March, and the last on the 29th of October. Landings were made on the rock during March on two days; April, two days; May, twelve days; June, eighteen days; July, twelve days; August, ten days; September, two days, and October, two days; in all sixty days, as compared with thirty-eight in the previous season. The workmen took up their abode in the barrack on the 26th of April, and were taken off on the 3rd of September; the working season on the rock extended over one hundred and thirteen days, exclusive of Sundays.

The foundation pit was completed and ready to receive the first course of the tower on the 24th of June, when the first stones were landed, and that course was finished on the 30th of June. The second course had been completed, and part of the third course built, when a severe gale on the 8th and 9th of July carried away part of the unfinished third course, and destroyed the landing cranes and apparatus connected with them. As soon as a landing could be effected, it was found that during this summer gale fourteen stones, each 2 tons in weight, which had been laid in Portland cement, and fixed in their places by joggles at a level of 35 feet 6 inches above high water, had been torn up, and eleven of them swept off the rock into deep water. The full importance of this occurrence cannot be realised until it is considered at what level above the sea these blocks were removed by a summer gale, with reference to works in situations of apparently similar exposure. Thus, for example, it appears that the level of 35 feet 6 inches above high water corresponds in the

Wolf, to 19 feet 2 inches above the top of the solid,
Bishop, to 16 feet 3 inches ,, ,, ,,
Skerryvore, to 4 feet 9 inches ,, ,, ,,

while at Dhu Heartach it is 28 feet 9 inches below the top of the solid.

Since the works were completed, a further proof of the extreme violence of the seas that assail the Dhu Heartach lighthouse tower has occurred. The lightning-conductor, which is on the lee side of the tower, is of copper, 1½ inch broad by 1 inch thick, fastened with countersunk screws, 5 feet apart, into a raglet 1⅝ inch broad by 1 inch deep, so that it is flush with the side of the tower. During a heavy storm, in November 1872, the con-

ductor was torn 3 inches out of the raglet, at the lower part of the tower, for a length of about 10 feet, one of the screws being wrenched from its socket; and at three other places—one of them being as high as the kitchen window, or 92 feet above high water—the rod was bent between the screws ½ inch out of the raglet.

Previous cases are not wanting where the sea has exerted great force at high levels—notably at North Unst lighthouse, built on a rock lying about ¾ mile off the northernmost of the Shetland Islands. Though the tower was founded at the level of 196 feet above high water, during a north-west gale it was subjected to seas of sufficient weight to overthrow the boundary walls, and force open the door of the house. And, again, heavy seas have struck the iron tower on the Fastnet rock, on the coast of Ireland, although founded on a rock the top of which is 70 feet above high water. In both cases the rocks present an almost perpendicular face of considerable height to the sea. At Dhu Heartach no such face exists; but it is believed that at no lighthouse tower hitherto constructed have such remarkable proofs of the violence of the sea at high levels been observed. This leads to the consideration whether there is any reason for expecting heavier seas at Dhu Heartach than at places having the same sea fetch.

If a model be made of the outline of the bottom of the ocean to the westward of Dhu Heartach, from the soundings in the Admiralty survey, it will be found that the lighthouse rock lies at the head of what may be termed a submarine valley, stretching seawards for a distance of 80 nautical miles to the 100-fathom line. It will further be found that the southern side of this valley is comparatively steep, the 30, 40, 50, 60, and 70-fathom lines being all drawn together, so as to form a rapidly rising slope of about 280 feet in height; while the northern side of the valley, which is formed by the Stanton Bank, with a depth of 30 fathoms on it, presents a somewhat similar outline.

The depth and extent to which the action of waves and tidal currents is affected by the configuration of the bottom are the points on which this question turns; for if waves "feel" the bottom in water of a depth of from 40 fathoms to 100 fathoms, a gorge of the nature described, besides admitting heavy seas to come nearer the shore before breaking than they otherwise would, must necessarily increase, to some extent, the height of those which enter its mouth. The following quotation from Professor Airy's article on "Tides and Waves," in the "Encyclopædia Metropolitana," is interesting as

bearing on this point:[1] "The horizontal motion of the particles of water next to the bottom, produced in shallow water by long waves, is proved to be sensible by the disturbance of the stones and sand at the bottom; and that the breaking over the edge of a shoal is stated as occurring on the edge of the bank of Newfoundland when the waves in general are high, although the depth on the shallow side is 500 feet, (that on the deep side being much greater). We may mention, on the authority of the best charts, that a similar breaking is observed about the line of 'no soundings' (that is, where the water suddenly becomes deeper than 600 feet) which at some distance borders the British Isles." Colonel Emy also maintains that motion may be observed at a depth of 500 feet.

The Author thinks it is impossible to doubt, that a funnel-shaped deep track, receiving directly the seas and currents of the Atlantic Ocean, must have some effect in concentrating the waves on the lighthouse rock at the head of this submerged valley, and may therefore account for the seemingly abnormal seas to which the tower is subjected. In this view the hidden outlines of the ocean bottom cannot fail to have a great effect, in determining the force of the sea as it is thrown on lighthouses and breakwaters. A careful study of the contour lines laid down from soundings is useful and interesting, but it is not till these contour lines have been modelled, in the same way as is often done in representing the hills and valleys of a country, that it is possible to realise to its full extent the influence of the ocean bottom on waves and undercurrents, or the importance of modelling the bottom of the sea, in order to obtain a correct idea of the probable effect of its outline. It also shows in a forcible manner how far a seaman may, on such a coast, be deceived, when trusting to soundings to indicate his position. The conclusion to be drawn from what has been brought forward is, that there is no mould, so to speak, in which all such lighthouse towers can be cast, but that each case demands a careful study of, and provision for, its own peculiarities.

A point of some interest still remains to be noticed. It has already been stated that, in carrying out the works, a deviation was introduced in the original design. The height of the solid portion was intended to have terminated at the thirteenth course, or 52 feet 10 inches above high water; but the experience of the two summer gales, in 1868 and in 1869, led to this part of the design being reconsidered. The result was that, to provide

[1] *Vide* "Encyclopædia Metropolitana," vol. v., p. 351*, col. 1. London, 1848.

against the still heavier seas of winter, it was deemed prudent to raise the level of the door 11½ feet higher than was originally designed, or about 64 feet 4 inches above high-water level.

The accompanying table shows the level above high water spring tides at which the solid portions of the following lighthouse towers terminate:—

Name.	Engineers.	Height of Solid Portion above High Water. Feet.	Ins.	Authority.
Edystone . .	Smeaton	10	3	Smeaton's "Narrative."
Bell Rock . .	R. Stevenson . .	14	0	Stevenson's "Bell Rock."
Wolf . . .	J. Walker and J. N. Douglass	16	4	J. N. Douglass, Minutes of Proceedings Inst. C.E., vol. xxx.
Bishop . . .	J. Walker . . .	23	0	Drawing by J. Walker.
Chickens . .	D. and T. Stevenson	21	0	Reports by D. and T. Stevenson.
Skerryvore . .	Alan Stevenson. .	30	6	Stevenson's "Skerryvore."
Dhu Heartach.	D. and T. Stevenson	64	4	Reports by D. and T. Stevenson.

This table is interesting as showing the views held by engineers in making their designs for different situations; and the experience gained at Dhu Heartach, as detailed by the Author, proves that, in situations so exposed, the engineer would greatly err if he relied on the elevation of the rock above high water as raising his work so much above sea risk.

To return, however, from this digression: immediate steps were taken to restore the cranes and to supply other stones in place of those which had been lost, but no landing could again be effected at the rock till the 16th of July, when building was resumed and continued without interruption till the end of the working season, the fifth course being completed on the 30th of August. The remainder of the working season was devoted to securing the courses already built, and removing the cranes, &c., in preparation for the winter months.

The anticipations of the Engineers in their first reports, as to the difficulties of landing, had been most fully realised. The consequence was that, at the close of this, the third season's work, all that had been accomplished by continued perseverance was the erection of the barrack, the preparation of the foundation, and the completion of the first five courses of the tower. On shore, dwelling-houses for five families had been finished, and the workmen had dressed seventeen courses of the tower.

The stones were dressed to their required shape, and built dry on the fitting platforms at Earraid. They were then transferred to lighters and towed out to the rock. The stone lighters were of 37 feet 6 inches keel, 12 feet 2 inches beam, and carried 16 tons. The steamer generally towed out two at a time, taking three hours to go out, and on some exceptionally fine days they succeeded in making two trips to the rock.

On a lighter being brought alongside and moored, a steam crane with a long derrick was employed to land the stones on the rock, and with the help of a steel spring attached to the hook, which took hold of the lewises in the stones, this could be done even when there was a considerable run. Immediately on being landed the stones were conveyed to their destined place in the tower by cranes and an inclined tramway, all worked by steam, and the stones were at once built into their places, as there was no means of storing or stacking them on any part of the rock so as to be safe in the event of a gale springing up.

The manner in which the stones were jointed and joggled is shown in Plate 2. Square joggles were employed up to the twenty-sixth course, when they were superseded by a ribbon joggle, measuring 2½ inches high and 8 inches broad. The double ribbon in the floor courses is particularly worthy of note, as adding much to the strength, and as not having been used before. Besides those of stone, joggles of cast and malleable iron, suggested by Mr. Alan Brebner, were used in the lower courses, to prevent them being washed away before there was any superincumbent weight to keep them down.

1870.

The first landing on the rock was made on the 14th of April, and the last on the 5th of October. The workmen took up their abode in the barrack on the rock on the 4th of April, and after a residence of nearly five months were brought off on the last day of August. During this season landings were made on sixty-two days as follows: April, seven days; May, nine days; June, twelve days; July, fifteen days; August, seventeen days; and October, two days.

Although the men were on the rock in the beginning of April, such was the state of the sea that no stones could be landed till the 6th of June; but after that date the weather became more favourable, and the thirty-first course, which raised the tower to a height of 48 feet above the rock, was finished on the 24th of August.

The dressing of the stones on shore was pushed vigorously on, the quarries turning out materials of excellent quality. Houses to accommodate seven families had now been erected, of the small stones produced in quarrying the large blocks for the tower.

Contracts were also entered into with Messrs. Dove and Co., Edinburgh, for the lantern, and with Messrs. Chance, of Birmingham, for the optical apparatus.

1871.

During this season landings were made on fifty-seven days, as follows: May, thirteen days; June, fifteen days; July, thirteen days; August, eight days; September, seven days; and October, one day. The first landing was effected on the 1st of May, and the last on the 10th of October. The men were taken off the rock on the 28th of August. The masonry of the tower was completed, as well as the whole of the dwelling-houses at Earraid for the lightkeepers and seamen.

1872.

The first landing was made on the rock on the 23rd of April, and on the 25th the workmen inhabited the barrack for the first time this season. The fitting up of the lantern, optical apparatus, fog bell, and internal finishings of the tower were completed, as also two beacons of Portland cement rubble, at the entrance of the Bay of Earraid, for the guidance of the attending vessel. The light, the centre of which is about 145 feet above the sea, giving a range, as seen from the deck of a vessel, of 18 nautical miles, was exhibited on the 1st of November. It is a first-order dioptric fixed apparatus, showing a white light excepting over an arc of seven points of the compass, viz., between the bearings S. by W. ½ W. and W. ½ N., which is red. The fog-bell machinery is of a somewhat novel construction, being so arranged as to produce a rapid succession of strokes, lasting for ten seconds and occurring at intervals of thirty seconds. This was adopted as a distinction from the fog-signal bell at Skerryvore, which gives a single toll every minute.

1873.

The barrack was taken down and some minor works were executed. The lower uprights of the barrack were left standing, as the expense of removing them would have been greater than the sum that would have been realised by the sale of the iron of which they are composed; and in the event of its ever being

necessary to communicate with the rock by means of the rocket apparatus they would be useful for making fast the cradle line.

From this narrative of the progress of the works, it will be seen that the month of June, which had been calculated upon as being fully available, afforded few opportunities for landing materials on the rock, and it was generally about the middle or towards the end of that month before regular progress could be made. But often when it was impossible to land stores or men, provisions and other small articles were, by hauling them through the surf, landed on the rock.

In addition to the lighthouse tower, the works include nine dwelling-houses on shore for the families of the lightkeepers and crew of the attending steamer, which also attends Skerryvore in winter and delivers stores to other lighthouses on the west coast during summer. The total cost of the works was £76,084 9*s.* 7*d.*, which may be approximately apportioned as follows:—

	£.	s.	d.
Tower, lantern, apparatus and fog-bell machinery . .	65,784	9	7
Shore establishment	10,300	0	0
	76,084	9	7

It need hardly be pointed out, that a comparative estimate of the cost of such works cannot afford any useful result, as the circumstances connected with their erection are in all cases so dissimilar, including the extent of the shore establishments, the difficulties of communication and therefore the time of execution, rates of wages, prices of materials, and other items of a similar nature, rendering comparison untrustworthy. The works were carried out by day wages, it being impossible to contract for such a work, and the isolated nature of the locality compelled the Commissioners to provide all the food necessary for the men by means of a store, and accommodation for them in bothies, which added considerably to the cost of the work.

The Author concludes this communication with the following quotation from the final report of the Engineers: "When it is considered that Dhu Heartach Rock is of small area, surrounded on all sides by deep water, and exposed to the swell of the Atlantic Ocean, that it is nearly 16 miles from the shore, and could only be worked on for about two months and a half in the year, we believe that the amount of work executed will bear favourable comparison with other undertakings in less exposed situations; while the fact that

the whole has been brought to a successful close without loss of life or damage to property bears ample testimony to the skill which distinguished the personal conduct of the rock work and shipping of this difficult undertaking; the general direction of the works being under Mr. Alexander Brebner, the masonry at the rock under Mr. Goodwillie, while the conduct of the shipping was under Mr. McGregor."

The communication is accompanied by a series of maps and drawings, from which Plates 1 and 2 have been compiled.

[Mr. J. N. Douglass

Mr. J. N. Douglass remarked that the Messrs. Stevenson were to be congratulated for having completed the work without loss of life or limb to any of the persons employed, and also for having adopted granite for the tower. No doubt the tower might have been constructed with wrought iron or cast iron, but, in doing so, little reduction would have been effected in the cost, while an annual outlay would have been involved for the preservation of the work, and there would have been a limit to its duration. The Author had furnished some interesting particulars relative to the heavy seas experienced at Dhu Heartach. The position of the rock and the nature of the soundings seaward were doubtless sufficient to account for heavy seas, but he did not consider there was evidence to show that heavier seas occurred there than at the Bishop or the Wolf rocks on the west coast of England, as might be expected by comparing the soundings. On the north-west, or most exposed side of the Bishop, at a distance of 4 miles, there was a depth of 50 fathoms, gradually shoaling to 30 fathoms close to the rock, which had a gradient to the westward of about 1 in 1. These were favourable conditions for heavy seas, and for the concentration of their force upon the building. Both at the Bishop and at the Wolf, where the soundings and gradients of the rock were similar, heavy seas rose several feet higher than the building before cresting; but, fortunately, they crested after they had passed the building. Such seas fell and were spent at about a cable's length from the tower. The destruction of the iron pile lighthouse first erected on the Bishop was due to unbroken seas striking the dwelling, the floor of which was 85 feet above high water and the surface of the rock. During a storm on the 30th of January, 1860, the fog bell, weighing 3 cwt., was torn from the bracket, on the lee side of the lantern gallery, 100 feet above high water; and during a storm in the winter of 1874–5 the heaviest seas experienced since the completion of the lighthouse in 1858 were encountered. On this occasion the tremor of the building was so great as to cause articles to leave the shelves. On his recommendation the building had since been strengthened by strong internal vertical and radiating ties of wrought iron secured to the walls and floors. At the Wolf, before the erection of the lighthouse, there was evidence of the enormous force of the heavy seas falling on it, in the breaking off, on three occasions, of the masts of the beacon—one of English oak and two of wrought iron, the last being 9 inches in diameter. He did not think that seas could fall so heavily on the Dhu Heartach rock as on the Bishop or the Wolf rocks; otherwise

he could not conceive it possible for the workmen's barrack to have withstood them. He preferred, for the form of the structure, a curve nearer that of the Edystone, with a comparatively larger base grasping the rock. The method of stepping, or offset courses, first adopted by the late Mr. James Walker, Past-President Inst. C.E., at the Menai lighthouse, combined the advantage offered by such a form for stability with that of a vertical wall in checking the tendency of heavy seas to rise to the upper and weaker part of the structure. The statement of the comparative height of the solid portion of the building above high water would, he thought, have been more complete if the height above the surface of the rock at the base of the tower had been given. Although, in the seven lighthouses referred to, the heights of the solid portion above high water were found to vary between 10 feet 3 inches for the Edystone and 64 feet 4 inches for Dhu Heartach, thus showing a difference of 54 feet 1 inch, the heights above the surface of the rock were respectively 32 feet and 12 feet—a difference of only 20 feet. He did not consider the erection of a barrack on the rock an economical arrangement for such a work. In addition to the first cost of the structure, the time in erecting it was not, he thought, compensated by any advantages, as, after the foundation of the lighthouse had been prepared, which should be accomplished by the time that a barrack could be erected, workmen were not required on the rock, except at such times as materials for the tower could be landed. He had always found that workmen could be got on or off such a rock whenever materials could be landed; and, in getting away with a sudden rising of the sea, his men were ready enough to be drawn off by a line, with a life-belt on, when the landing boat could no longer approach the rock with safety. With regard to the conveyance of workmen and material to the rock, instead of the tug and barges that had been described (and which had been adopted in the cases of the Bishop and the Wolf), he preferred two screw steamers, as had been employed at the Great and Little Basses lighthouses, off the south-east coast of Ceylon.[1] These vessels, carrying steam machinery for the purpose, were more speedily loaded at the workyard and moored at the rock; the material was more rapidly landed there; and they were safer at sea in rough weather than a tug towing barges. He agreed with the Author that it was difficult to contrast the cost of the work with that of other works of a similar character; but such comparisons must be made.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxviii., p. 56.

It was, therefore, only fair to submit a work of that kind to the usual standard of estimates, namely, the price per cubic foot of the work executed. The cost of the Dhu Heartach lighthouse, irrespective of the shore establishment, was stated to have been £65,784 9*s.* 7*d.* The weight of the structure was 3,115 tons, and, taking 13½ cubic feet of granite to the ton, the cost amounted to £1 11*s.* 3½*d.* per cubic foot. The cost of the Bishop lighthouse was £34,559 18*s.* 9*d.*, or 19*s.* 7½*d.* per cubic foot, which was 37½ per cent. below the cost of the Dhu Heartach. When it was remembered that part of the foundation of the Bishop was laid at 1 foot below low water spring tides, and the foundations of the Dhu Heartach at 32 feet above high water spring tides, he thought the cost of the latter did not compare favourably with that of the former. True the Bishop had been completed in 1858, when wages and material were lower than at present; but the improvements since effected in steam appliances for executing such works had fully compensated for this increase.

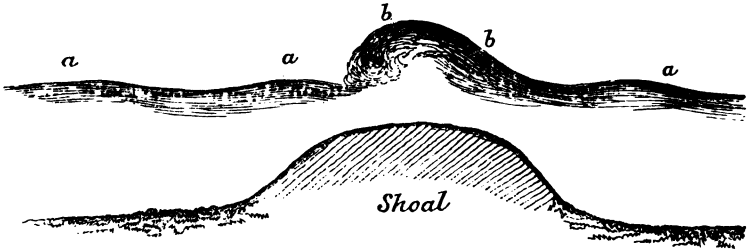
Mr. LONGRIDGE asked upon what evidence Mr. Douglass based his statement as to the height to which the sea rose against the Bishop lighthouse. According to that statement, as he understood it, the solid wave rose 70 feet against the lighthouse, and continued rising 30 feet higher than the top, making a total height of 160 feet above the rock. The depth of water being 34 fathoms, and the slope of the rock 1 in 1, he could not conceive how such a thing could happen. He had paid some attention to the height of the waves in the Atlantic, and did not think he had ever seen a wave higher than 35 feet in the deepest water. The only people who had seen the sea rising against the Bishop lighthouse were probably the keepers, who had been no doubt considerably frightened, and had exaggerated the height of the water.

Mr. REDMAN thought that there had been some misapprehension as to the statement of Mr. Douglass. The height of the waves in the Atlantic, from the trough to the crest, had been variously estimated at from 30 to 40 feet. The waves striking the British coast were from 20 to 30 feet high. Mr. Douglass, he presumed, did not mean that the waves breaking upon the lighthouse were 60 or 70 feet high from the trough to the crest, but that from the configuration of the bottom and the slope of the face of the submerged rock at an angle of 45° the water was shot over in the manner he described; and considering the general accuracy of Mr. Douglass's remarks on such subjects, he had no doubt that the account he had given was a faithful one. The site of the Dhu Heartach lighthouse was peculiar; and at Skerryvore, which was contiguous to it, a pressure of 3 tons to the superficial foot, being the greatest amount

ever observed, had been recorded by the dynamometer of Mr. Thomas Stevenson. The peculiar conformation of the bottom reminded him of a diagram he recently presented to the Institution,[1] showing how different were the conditions attendant upon various national harbours. His attention was particularly directed to that subject in the discussion on the Alderney breakwater, when he remarked upon the fact that that breakwater, being in a condition somewhat similar to the site of the Bishop lighthouse, with 120 feet depth of water, and with an offing to the West Indies, was not comparable to the other harbours of the country, and in the discussion on the Holyhead New Harbour his remarks were embodied in a diagram. Undoubtedly the facts recorded by the Author on the rock in question should be regarded as the results of its exceptional position; because, as Mr. Douglass had remarked, although it was in an exposed part of a peculiar ocean, the foundation was 35 feet above the level of high water.

Sir JOHN COODE, while fully agreeing with the Author as to the importance to be attached to the configuration of the bottom in its effect upon the height of waves, did not think that the diagram quite bore out the view which had been put forward. The Dhu Heartach lighthouse was in 30 fathoms of water; the next contour was 40 fathoms, a difference of only 60 feet in about 5 miles, or 12 feet per mile. Such an inclination—1 in 440—was not, he thought, sufficient to affect the rise of the waves. He believed Mr. Longridge must have been misled by not distinguishing between undulations in deep and in shoal water. Of the difference between the two he had once had a good illustration. Looking seaward at

FIG. 1.



a point where his eye struck the horizon 4 miles off, the general configuration of the sea surface was a slight undulation, as at *a a a*; but at a point where there was a shoal, with 2 fathoms of water over it, the line was as at *b b* (Fig. 1). This would give some

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 121.

idea of the effect of the gradual shoaling of the bottom upon the height of sea waves. He thought great credit was due to Messrs. Stevenson for the manner in which the work had been carried out under exceptional difficulties, and the more so that it had been executed without loss of life or injury to any individual engaged upon it.

Mr. Bramwell said Mr. Longridge appeared to think that there must be some mistake in the statement that a solid wave could rise 100 or 130 feet above the water-level, because the height of the waves in the Atlantic did not exceed 35 feet. The Author had referred it to the underground configuration. Mr. Bramwell was not in a position to say whether the configuration was such as to justify the conclusion drawn from it; but it was perfectly easy to suppose that there might be such a configuration. He might instance two well-known cases of high tides. The tide at Chepstow had been variously stated at between 40 and 50 feet, and that was at the head of a stream where the rise and fall at the mouth was not one-half. The excess of the rise was due to the momentum of the water in that particular shape of channel, which momentum must be spent in some way. Again, there was the still more remarkable case of the Bay of Fundy. At the head of the bay the rise and fall were still greater than at Chepstow, sometimes amounting to 60 or 70 feet, and at the mouth they were only 8 feet. Those two cases were produced entirely by the configuration of the channel; and in the case of a submarine channel of adequate shape, and a wave coming along with great velocity, it appeared to him that the same rule would subsist, and that such results might be obtained as had been described. One point was quite clear: Whatever the alarm of the keepers, and however they might have exaggerated, an inanimate bell, which could not feel fear and could not exaggerate, hanging from the gallery, was torn away by something, and that something, depend upon it, was not mere spray, but was a strong body of water.

Mr. D. A. Stevenson observed, through the Secretary, in reply on the discussion, that Mr. Douglass, in comparing the cost of the Bishop and the Dhu Heartach lighthouses, had not elucidated what could be of any real practical importance to Engineers. The particulars of each case, as to facilities for getting materials, for accommodating workmen, and, above all, the "regulating prices" of the period, must obviously be taken into account before any useful result could be attained. At Dhu Heartach the workmen had to be accommodated on an uninhabited island. The Bishop light-

house, moreover, was completed in 1858, after a period when prices were abnormally low, while the Dhu Heartach lighthouse was finished in 1872, when the prices of materials, provisions, and labour had been exceptionally high. The rise in these items, even between 1866 and 1872, had been, for provisions, 17·3 per cent.; for materials, 22·6 per cent.; and for wages, 14 per cent. No one would contend that the Bishop lighthouse could be built, at present prices, for £34,559.

Both Mr. Douglass and Sir John Coode seemed to have thought that it was the gradually sloping form of the bottom to which the Author attributed the peculiarly heavy action of the sea at Dhu Heartach. But this was not the case; it was to the submarine valley leading deep water up to the lighthouse, and increasing the height of the waves by its converging and comparatively precipitous sides, that the violent action was attributed. He had consulted the Admiralty charts before completing the Paper, and had found that neither the site of the Edystone, Bishop, Bell Rock, or Skerryvore lighthouses had any similar submarine feature open to the waves which assailed the towers on those rocks.

No. 1,427.—"On the Changes in the Tidal Portion of the River Mersey, and in its Estuary." By JAMES NELSON SHOOLBRED, B.A., Assoc. Inst. C.E.[1]

THE river Mersey, formed by the junction of the Goyt and the Etherow a few miles above Stockport, in Cheshire, traverses between this town and the sea a gently undulating agricultural district, composed geologically of the New Red Sandstone formation; and therefore tending during floods to cause the river to carry with it down to the sea a large quantity of soft, friable detritus. The Mersey first meets the action of the tide at Woolston Weir, 4 miles above the town of Warrington, and about 35 miles from its commencement; during which distance it is joined by its principal tributaries, the Tame, the Irwell, and the Bollen. The entire area drained up to this point by all these streams is 765 square miles; of which 270 miles are of the soft Red Sandstone formation, and the remainder of the harder Millstone Grit and of the Coal Measures. The downward course of the Mersey, past Warrington and on to Runcorn (Plate 3), continues, though tidal, to present nearly the ordinary features of an inland river, with the exception of an enlargement in width above the narrow gap presented at the latter place. Just below Runcorn, however, between Hale Head and Weston Point, the river suddenly emerges into a large, broad, sandy expanse (sometimes called the Upper Estuary); it is at the extreme south-east corner of this basin that the river enters it. While at the south-west corner, near the village of Frodsham, and at no great distance from the entrance of the Mersey stream, the estuary also receives the waters of the river Weaver. This stream, together with its chief tributary, the Dane, also flows almost entirely through the soft Red Sandstone, and combined they drain an area of 520 square miles. This broad expanse of the river Mersey gradually widens out from nearly 1¾ mile at its head, to 3 miles between Ince Marshes and Dungeon Point, whence it gradually diminishes to 1¼ mile at its lower end, between Dingle Point (the southern extremity of the town of Liverpool) and Bromborough on the Cheshire shore. The length of the basin is about 11 miles.

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[1] The Author became a Member by transfer on the 9th of May following.

The appearance and character of the remainder of the course of the Mersey, flowing between the towns of Liverpool and Birkenhead, are very different from that just described. It consists of a deep channel, scoured out of the Red Sandstone, and kept clear of sand by the force of the tidal current pouring through it in each direction. Its width gradually contracts from the Dingle till reaching Seacombe Narrows (between Seacombe Point and the Prince's Dock), where it is only about 1,000 yards across. Thence to the Rock Lighthouse the channel gradually widens out, particularly on the Lancashire side. The Mersey is affected by the tide, from the Rock Lighthouse to Woolston Weir, a distance of about 32 miles.

The form presented by the river to the action of the tidal wave has been briefly described as a bottle or flask; having an elongated bell-shaped mouth, leading through a contracted throat into a broad, shallow lake, and with two (comparatively) small streams of fresh water (the Mersey and the Weaver) constantly flowing into the upper end of this lake. The approach of the tidal water to the mouth of the river Mersey, as well as its egress from it, seems, of late years at least, always to have been through two distinct channels, each starting from the deep water of the Irish Channel at different points, and leading across the sands of the estuary to the mouth of the river, at which point they become united. One of these (the Rock Channel), communicating with the deep water near the mouth of the river Dee, skirts the Cheshire coast at the extremity of the Wirral Peninsula, and, passing close to the Rock Point, joins the Mersey at its mouth almost at right angles to the course of the river. Its length seems always to have been about 8½ miles. While the other, the Crosby Channel, the larger outlet of the two, lies in direct continuation of the river channel, and keeping the Lancashire shore till about opposite the village of Formby, effects its communication with the open sea by a sudden turn to the westward. Its length is generally about 10½ miles.

The geographical area embraced by the subject of this Paper may be considered as coinciding with the limits assigned by Parliament to the Port of Liverpool, and to the Conservancy of the River Mersey. The limits of the Port of Liverpool for customs dues were defined by an Act of Charles II., passed in 1680, to be "from the Red stones in Hoylake, on the Point of Werral, southerly to the foot of Ribble water in a direct line northerly, and so upon the south side of the said river to Hesketh Bank easterly, and thence all over the River Mersey to Warrington and Frodsham

Bridges." These limits nearly coincide with those assigned to the Mersey Conservancy Board.

Little importance was attached to the conservancy of the navigation of the river Mersey till about 1825, when the strand abutting upon the river began to increase in value. Considerable litigation took place from that time between the various claimants, the Duchy of Lancaster, the Corporation of Liverpool, the Mersey and Irwell Navigation Company, &c.; till in 1842 the question was definitely set at rest by the passing of the Mersey Conservancy Act. The Commissioners appointed by it were the First Lord of the Admiralty, the Chancellor of the Duchy of Lancaster, and the Chief Commissioner of Woods and Forests.[1] Their purpose is "to preserve the navigation of the river Mersey from Warrington and Frodsham bridges to the sea," and to guard against encroachment on the tideway of the Mersey beyond the line of the high-water mark of a tide, uninfluenced by the wind, of the height of 21 feet on the sill of the Old Dock at Liverpool. The post of "Acting Conservator" has been filled by Admiral George Evans, Assoc. Inst. C.E., ever since the formation of the Board, with the exception of a short period at the commencement, when the late Admiral Fitzroy occupied the position.

Though the Mersey Conservators are the legal guardians of the river, and alone are empowered to preserve it against encroachments, yet those who actually buoy and preserve the channels for navigation are, the Mersey Docks and Harbour Board for the sea-channels across the estuary, and the Bridgewater Navigation Company for the Upper Mersey, *i.e.*, from Garston up as far as Runcorn; while the owners of the Garston Docks and the Ellesmere Port Docks buoy the approaches to those docks. The Mersey Docks and Harbour Board was appointed by Parliament, in 1857, custodian of the docks both on the Liverpool and on the Birkenhead side of the river; for their construction, as well as for their maintenance. It consists of twenty-eight members, twenty-four being elected by the dock ratepayers, and four being appointed by the Crown. This Board succeeded to the duties, and acquired the rights of levying the harbour and dock dues over the Lower Mersey possessed by the Corporation of Liverpool, as trustees of the Liverpool Docks, and administered by the Dock Committee; a body composed partly of ratepayers, partly of nominees of the Corporation, in which latter body the entire control of the Liverpool Docks

[1] By an Act passed in 1872 the President of the Board of Trade has taken the place of the Chief Commissioner of Woods and Forests.

and dues had originally been vested. The right of levying town dues on vessels visiting the ports of the Mersey above Liverpool was in 1865 purchased from the Corporation of Liverpool, and vested in the Upper Mersey Trust Commissioners, a body representing the different commercial interests along the Mersey above Liverpool, having the chairman of the Bridgewater Trustees at its head. Their power of levying dues extends no lower down the Mersey than an imaginary line drawn from Eastham to Garston, and includes the docks at the latter place, as well as those at Ellesmere, at Weston, at Widnes, and at Runcorn. It is understood that a large portion of the sum paid to the Corporation of Liverpool for the commutation of the dues has already been paid off by the Trustees, and that before long the Upper Mersey will be free from all dues, excepting the one for lighting paid to the Mersey Docks and Harbour Board. The buoyage of the channel from Garston to Runcorn, which is perpetually altering its course, is, however, gratuitously undertaken and maintained by the Bridgewater Navigation Company, who of course are largely interested in the safe maintenance of this portion of the river.[1]

Maps of the River Mersey.

Apart from some small maps of the town of Liverpool and its neighbourhood, the first record giving any information respecting the condition of the river Mersey with soundings of depths, &c., is one published in 1765 by John Eyes, a gentleman belonging to a family of surveyors, the result of whose labours is a series of maps and charts, both of the river and its estuary, commencing in 1736, and extending nearly to the end of the century. James Finchett also published a chart of the river Mersey in 1798, as did Gore and some others subsequently. None of these records, however interesting they may be, are either sufficiently extensive in the area comprised, or of such accuracy as to form a basis for a comparison such as is proposed in this Paper.

The first thoroughly accurate survey was that undertaken in 1819–21 for the Corporation of Liverpool by Mr. Francis Giles, extending from the mouth of the river up to Warrington and Frodsham bridges, the then southern limits of the Port of Liverpool, and which have since similarly been retained by the

[1] There is at present before Parliament a Bill, entitled "Upper Mersey Navigation," to create a Commission for the Upper Mersey, empowered to light, buoy, and improve it, and to levy tolls for the purpose.

Mersey Conservancy Act. Since that date only two complete surveys of the river have been made, viz., one by Lieutenant Parks, R.N., in 1861, and the other by Captain Hills, R.N., Assoc. Inst. C.E., in 1871. Both were undertaken at the instance of the Mersey Docks and Harbour Board; and they were so carried out as to afford special means of comparison with the one of 1820 and with each other. All three comprehend a similar extent of river, and their levels are referred to the same datum. This datum, used also for the soundings of the estuary charts, is the level of the sill of the Old Dock, the first of the Liverpool docks (and indeed the oldest in England), constructed by Mr. Thomas Steers in 1709. In 1826, when the dock was filled up, this level was carefully removed to the Canning Dock, and subsequently to the river face of Canning Island, between the entrances to the Canning Dock, which replaced the Old Dock. The index of levels above the Old Dock sill is there legibly marked, and is easily visible to all passing up or down the river.

The three surveys of 1820, 1861, and 1871 form therefore the bases of comparison in this Paper, and they are each referred to in the comparative longitudinal and cross sections, and in the plan of a portion of the river. Besides these three complete surveys, others not presenting similar facilities for comparison, and extending only over a portion of the same area, were executed, in 1835, by Lieutenant (now Admiral Sir H. M.) Denham, F.R.S., Assoc. Inst. C.E., the first Marine Surveyor to the Port of Liverpool, by Lieutenant W. Lord, also Marine Surveyor, in 1852, and by Mr. Robison Wright in 1857. This last presents special facilities for comparison, but unfortunately it does not extend into the upper reaches of the river above Runcorn. Reference, however, will be made to these surveys when possible.

The period of time, therefore, during which, with the above data, it will be possible to record with accuracy the various changes in the river portion of the Mersey may be assumed as extending back for sixty years.

Charts of the Estuary.

The earliest existing record of the Mersey estuary is a chart in "Great Britain's Coasting Pilot," by Captain Grenville Collins, R.N., in 1689, showing the coast from Chester Bar to Formby Point; and also another in the same work of Chester Water. In 1736 Messrs. Fearon and Eyes issued a chart, carefully prepared with the aid of Hadley's sextant, just then beginning to be used.

Mr. John Eyes issued subsequent editions with alterations and improvements in 1755 and 1767. Mr. P. Burdett published one in 1771; and in 1794 one by Messrs. Laurie and Whittle appeared. These charts, with a few others, chiefly adaptations of them, contain all the information which existed till the commencement of this century. In 1813 the first systematic survey was undertaken by Mr. George Thomas, R.N., at the instance of the Admiralty, for the Dock Trustees. In 1835 Lieutenant Denham, also under the direction of the Admiralty, and of the Dock Trustees, published his first chart, which was followed afterwards by others; these have since been continued regularly by his successors in the Marine Surveyorship of the Port of Liverpool, Lieutenant W. Lord, R.N., Lieutenant M. Parks, R.N., and Staff Commander Graham H. Hills, R.N., the present Marine Surveyor to the Mersey Docks and Harbour Board.

They thus present a ready means of comparison with those of the present day. Although the earlier charts of the estuary are sufficiently precise to trace back for nearly two hundred years any great changes in the course of the sea channels, as well as the position and approximate area of the sandbanks (in themselves a matter of great interest to science), yet information of an accurate and precise nature as to the changes taking place exists only for about sixty years back; the same period nearly as in the case of the tidal portion of the river.

Comparison of the Changes in the Tidal Portion of the River Mersey.

The powers conferred by Parliament upon the Conservators of the Mersey are limited by the high-water line of a tide, uninfluenced by the wind, of the height of 21 feet on the sill of the Old Dock at Liverpool.

This is the typical equinoctial spring tide of the Mersey, and is surpassed in range by few tides in the year. The low water of this tide is considered as 10 feet below the level of the Old Dock sill. The low-water features shown in all the sections and plans of the river (Plates 3 to 7), as well as in the more recent charts of the estuary, are those corresponding to this level. The contour line of the high water of this 21-feet tide has been accepted in all the modern surveys of the river as the limit of the area of its tideway. This contour line, within the mouth of the river and up to Warrington and Frodsham bridges, is set down at the present

time by the Marine Surveyor as slightly exceeding 74 lineal miles. The areas contained within the 21-feet tidal limit, as nearly as can be ascertained, were at the respective dates:—

	Statute acres.
In 1820 (Giles)	23,474
„ 1835 (Denham)	23,062
„ 1861 (Parks)	22,584
„ 1871 (Hills)	22,322[1]

This diminution in the high-water area between 1820 and 1871 of 1,152 acres, is due principally to the extension of the Liverpool Docks, which absorbed 775 acres between these dates (156 acres had been previously taken by them); the closing up of Wallasey Pool (in 1848) took a further amount of 170 acres; and the remainder has been inclosed mainly for the railway embankment and the docks at Runcorn and at Widnes, and for the docks at Weston, at Ellesmere Point, at Garston, and for other reclamations. Comparatively little change has taken place in the confining high-water limits in the other parts of the river, whether by the erosion of the low red-sandstone cliffs, or by the change in position of artificial embankments. The most noticeable alteration has been the steady, though slow, lineal increase of the embankments, and the consequent diminution of the cliffs. In the Report to the Mersey Docks and Harbour Board for 1861 it was estimated, that nearly 50 miles of walls and embankments existed, as against a little more than 24 miles of cliffs and shelving shore; while in 1871 the corresponding Report finds the former to have increased by about 3 miles, and the latter to have diminished by nearly this amount.

Lieutenant Parks found it necessary to apply a correction to the levels of Giles' survey in the upper portions of the river, between Hale Head and Warrington. On the 1820 survey it is stated "that the high water of spring tides generally flows at Weston Point 1 foot, and between Runcorn and Warrington 1 foot to 1 foot 6 inches higher than at Liverpool," *i.e.*, that the high water from Hale Head to Warrington was assumed to be practically horizontal. Captain Denham in 1837, in his memoir to the British Associa-

[1] It may be interesting here to remark that, at the same date and on the same authority, the total area covered by the typical equinoctial neap tide (with its high-water line 10 feet above the Old Dock sill, and its low-water one at the Old Dock sill level) was 17,722 statute acres; or 4,600 acres short of that covered by the above-mentioned equinoctial spring tide.

tion for the Advancement of Science,[1] Mr. J. M. Rendel in his evidence before Parliament relative to the Birkenhead Docks in 1844, as also Lieutenant Parks in 1861, and Captain Hills in 1871, all show that the rise of the tide between Runcorn and Warrington is considerably in excess of that stated by Giles. The Author, from his own experience, and by the aid of the Ordnance levels, feels that he can safely confirm the statements of Lieutenant Parks and of Captain Hills as to the rise of the tide at Warrington and in the upper reaches of the river.

That the levels of the 1820 survey cannot have been correct in the higher portion is proved by the fact that, had the apparent subsequent rise in the high-water levels actually taken place, the low-lying lands in those parts would, in 1837, 1844, 1861, and 1871, have been submerged by the tide; which was not the case, as the actual surface limit attained by a 21-feet tide is almost identical now, in these upper reaches, with what it was in 1820, and has continued so throughout the entire interval. It must be remembered also that Giles in 1820 had not the assistance of the Ordnance levels, which were largely taken advantage of as a check in the surveys of 1861 and 1871; especially when this discrepancy in the levels of 1820 was discovered.

Having thus fixed the area of the tideway to be compared, and before proceeding to examine the changes which have taken place within its limits, it will be advisable, in order to attach to each of the various changes its true value and importance, to endeavour to note the position in which each has occurred as regards the river itself. This will best be done by observing, which a glance at the map (Plate 3) will show, the main divisions into which Nature itself has divided the river; each division differing widely in character and in circumstances from the others. These may be taken as three in number, viz.:

First division.—Rock Lighthouse to the Dingle; the inlet and scouring straits.

Second division.—The Dingle to Hale Head; the broad tidal reservoir or Upper Estuary.

Third division.—Hale Head to Warrington; the narrow, semi-tidal portion.

The character of the first division, a deep channel scoured clean out of the red-sandstone bed, shows that its duty is far different

[1] *Vide* Report of the British Association, vol. vi., 1837. Transactions of Sections, p. 85.

from that of the broad expanse of the second one with its constantly shifting sands; which again varies much from the tortuous course of the upper division, where the influence of the tidal current is greatly impaired and in some parts hardly felt at all.[1] The area of the tideway of the first division is at present about 3,100 acres; of the second, 15,800 acres; and of the third, 3,400 acres.

To afford a means of accurate comparison throughout the river, in 1861 no less than fifty-four cross sections were made, coincident, or nearly so, with cross sections taken in 1820; and in 1871 the same course was again adopted. Twenty-three of these occur in the first division, fourteen in the second, and seventeen in the third. From these coincident cross sections a number of comparative ones have been prepared of the three periods (Plate 5). They extend from the mouth of the river up to Garston, at regular intervals of 900 yards below the Dingle Point (No. 47) and above that place of 1,300 yards; it being considered that the lower part of the river was likely to present the greatest amount of interest, both in an engineering and in a commercial point of view. A comparative longitudinal section (Plate 5) shows the greatest depth of water at each cross section, and illustrates any alteration in the navigable channel at any particular point.

A summary of the result of the comparison of the cross sections taken in 1820, 1861, and 1871 is shown in Table A in the Appendix. The area of section compared in each case has been the tideway in 1871 with the condition of the same portion of the river at the two previous epochs, *i.e.*, the curtailed tideway as now left, after making allowance for the artificial abstractions for docks and other purposes. Inasmuch, however, as the total of these abstractions is in the second and third divisions so insignificant, compared to the remaining area, that the tideway may still in each of those divisions be looked upon as intact, and that even in the first division the curtailment of the tideway of the river proper (*i.e.*, by the Liverpool Docks) amounts only to 6 per cent. of the sum of the entire sectional areas in 1820, or to 5·87 per cent. of the cubical contents at that period,[2] it will readily be seen that the exact comparison of the condition of the entire river in 1820 and in 1871 may without difficulty be arrived at.

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[1] In the Reports of the Marine Surveyors appended to the surveys for 1861 and 1871, the first division is formed into two, as is also the third division, making in all five divisions. For the purposes of comparison in this Paper three divisions, however, appear preferable on the score of simplicity.

[2] Appendix, Table B.

As regards the first division, it is satisfactory to notice that, after more than fifty years' experience, during which the requirements of commerce have been satisfied by yielding a considerable portion of its bed for docks, the former condition of the present tideway has not merely been maintained, but has been somewhat improved.

There are, however, one or two points in this division—as to banks and shoals—which have been, and still continue to be, causes of solicitude. The chief of these is the well-known Pluckington Bank, which threatens seriously to interfere with the entrances to the more southern of the Liverpool Docks. The earliest reliable record of the river, that of John Eyes in 1765, shows this bank as isolated and separated from the Lancashire shore by a narrow channel. It seemed to be abreast of the present Canning Dock, in a somewhat more northerly position than at present. Giles, in 1820, surveyed this bank; and Captain Denham, and his successors in the Marine Surveyorship, have also done so repeatedly. In the opinion of Captain Denham, as expressed in a communication to the Corporation of Liverpool, the Pluckington Bank is formed during the ebb tide, owing to that portion of it which is flowing along the Lancashire shore being deflected by the projecting rocks of the Dingle Point towards the Cheshire side. The effect of this diversion has been to weaken the tidal current so much as to allow the silt, carried by it in suspension, to be deposited along the face of the southern Liverpool Docks; while at the same time it is so enfeebled as to be unable to carry off the silt driven out from the docks. On the enlarged map of the river (Plate 4) the extent of this bank between the high-water and low-water limits of a 21-feet equinoctial spring tide, is shown at each of the different periods compared.

The area of this bank, exposed above the level of 10 feet below the Old Dock sill, was:

	Square yards.	
In 1820 (Giles)	417,139	being an increase of nearly 50 per cent.
„ 1861 (Parks)	624,744	
„ 1871 (Hills)	749,361	„ „ „ 20 „

or an increase of nearly 80 per cent. since 1820.

A comparison, however, of the cubical contents of the bank above the same low water gives the following results:—

	Cubic yards.	
In 1820 . . .	917,820	being an increase of 20 per cent.
„ 1861 . . .	1,103,420	
„ 1871 . . .	1,298,220	„ „ 17 „

or an augmentation of 41 per cent. in 1871 over the quantity in 1820.

If instead of the above level of low water, the 2-fathom contour line below it be adopted as a datum, these percentages of increase at the later periods diminish materially, owing to the fact that the edge of the bank below low-water mark deepens very quickly. Captain Denham paid considerable attention to this bank, and endeavoured to impress upon the Corporation of Liverpool the importance of the gradual augmentation in its size. He surveyed it in 1834 and on several subsequent occasions; as did his successor, Lieutenant Lord, in 1852; and again Mr. J. Robison Wright, in 1857. The Author understands that in each case there was a considerable increase in the area of the bank over that shown by the preceding survey. A noticeable feature in the appearance of the bank, when dry at low water, is its gradual progression southward, and its extension at the south-west corner; while at the same time, though in a lesser degree, its northern extremity diminishes in width and tapers away. This gradual diminution at the northern extremity is due probably to the action of the flowing tidal current, increased in velocity in consequence of the continual extension northward of the river wall of the docks on the Liverpool side, and to that current being less deflected towards the Cheshire shore since the closing of Wallasey Pool.

Many suggestions have been made for removing Pluckington Bank, either by dredging, or by blasting (for a close inspection discloses the underlying rock in parts), or by other means. Captain Denham advocated an extension of the river wall southward up to the Dingle Point, and past it for about 1½ mile along the shore in front of the cliffs to Otterspool; thus cutting off the rocky recess or bay, called Knott's Hole, on the south side of the Dingle Point; which in his opinion caused the deflection of the current and conduced largely to the formation of the bank. Messrs. James Walker and J. B. Hartley, in a report dated the 21st of December, 1857, to the Birkenhead Dock Committee, advocated, in addition to Captain Denham's proposition, that a wall should be continued "from Birkenhead or Tranmere Ferry, to Rock Ferry upwards, so as to cut off the indraft caused by the bay to the south of Tranmere, and keep the flood tide in a straight course." In the last Liverpool Dock Act (1873) the present Engineer of the Mersey Docks and Harbour Board, Mr. G. F. Lyster, M. Inst. C.E., proposes partially to get rid of the inconvenience of the bank by avoiding it. Thus the proposed extension includes a means of

intercommunication between the southern docks, whereby vessels from the docks immediately behind the Pluckington Bank, the entrances to which it impedes, will have access to the river at times when, owing to the weakness of the tides, ingress to those docks is impossible.

Two other points in this division of the river, to which attention has at times been drawn, are the Low-water Basin at Birkenhead (now closed in, and being converted into a dock), and the sandbank along the river wall between the Low-water Basin and the Morpeth Dock. Very full information as to the former of these is contained in Mr. Ellacott's Paper[1] on that basin, and the discussion upon it. As regards the latter, not much more can be said than that it is of inconsiderable extent; that it formed rapidly after the closing up of Wallasey Pool, until about 1857, when it attained its maximum height of about 1 foot below Old Dock sill; and that since that time it has remained in about a stationary condition.

In the second division (the large tidal reservoir) the most noticeable fact is the retrogression in its condition since 1861; it having deteriorated during the ten years subsequent to that date no less than 7·48 per cent.; whereas in 1861 it had improved to an extent of 0·14 per cent. on its state in 1820. The adverse action in this division is considered however by the present Marine Surveyor, from later observations (1873), to have been superseded by one of an opposite tendency. Though the sectional areas in this division may in some parts show a diminution, yet the depths of the channel generally have not deteriorated. Indeed it is stated by Captain Foulkes, of Runcorn, for many years and until lately in charge of the buoyage of the Upper Mersey, under the Bridgewater Trustees, that the channel up to Runcorn is generally much improved; so much so that vessels of 400 to 500 tons burden are now able to get up there, while twenty-five years ago none over 250 tons could reach that place. The navigable channel throughout this broad estuary is so constantly changing, in consequence of the extremely mobile character of the sands forming the basin, that in order to keep it properly buoyed the Bridgewater Navigation Company find it necessary to have a monthly survey made of the channel. This extreme shiftiness of the sands is due, no doubt, to the enfeebled action of the tidal current expending itself over this broad expanse, checked and counteracted as it is by the land water constantly flowing in at the upper end, and bringing down

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 518.

with it the detritus and mud from the upper and fluvial portions of the river Mersey.

Another cause of the deterioration of the tideway of this district is the erosion, always going on, of the low clay cliffs which occur in many parts along the shores of this division, such as between the Dingle and Garston, and up to Dungeon Point, at Hale, at Hooton, &c. The cliffs vary from 5 to 40 feet in height. Their bases are acted upon by all the tides that reach them; wind, rain, and frost attack their faces, till at length the height of cliff—its base eaten away—falls into the streamway, and the detritus is carried away by the tide to further feed the shoals and banks of the river. The rate at which this damage goes on varies according to circumstances and to locality; opinions also differ considerably as to the quantity of erosion which annually takes place. In the report to the Mersey Docks and Harbour Board upon the survey of 1861, it is stated that the damage of encroachment, on the average, amounts to 1 foot per annum. Again, in 1871, Captain Hills considers this average amount fairly represents the facts, though he mentions cases in which the annual encroachment has been considerably in excess of it. Admiral Evans, the Acting Conservator, in his annual reports to the Conservancy Board as to the condition of the river, has repeatedly complained of the unchecked wasting away of the cliffs near Hooton and elsewhere (as much as 4 feet in less than a year), and of the deterioration thereby of the channel up to Ellesmere Port. Mr. Joseph Boult also, a gentleman well known for his scientific researches as to the history and condition of the Mersey, in a recent Paper on "The Deterioration of the Mersey," gives instances, at Speke and at Hooton, where as much as 3 feet, 4 feet, and even more per annum have crumbled away. The present Marine Surveyor, in his report on the survey of 1871, estimates the total annual accumulation in the tideway from this cause as equal to a deposit of 1 foot in depth over nearly 25 acres.

In the third division, an inspection of the comparative table of areas shows that, though in 1871 there was a loss of sectional area over what had existed in 1820, yet the amount of deterioration was less (12·27 per cent. as against 13·48 per cent.) than in 1861; indicating an improving tendency during the last decade. This state of affairs may, on the whole, be considered satisfactory, seeing that this part of the river forms a species of breakwater whereon the momentum of the tidal wave is expended, and is only partially acted upon by the tide. The flood during spring tides does not last more than three-quarters of an hour at the upper end, at

Warrington, while the neap tides affect but little more than the lower half of the district.

Before leaving this branch of the subject, it may not be inappropriate to say a few words on a matter closely connected with it, viz., the disposal of the mud dredged from the Liverpool and other docks on the Mersey.

The Lancashire shore, owing to the prevailing direction of the strong winds being from the west, becomes the exposed or lee side of the Mersey. Large quantities of the sand and detritus, held in suspension by the tidal water, are driven into the Liverpool docks and deposited there, especially during the violent westerly gales. These docks are continually being cleaned, each in turn, by steam dredgers, and the mud conveyed thence in barges and deposited in the river in mid-stream between Egremont and Seacombe, under the authority of an Act of Parliament passed in 1825. This method of disposing of the mud has been repeatedly adverted to by Admiral Evans in his annual reports, and he recommends its removal from the river. The annual quantity of material dredged from the Liverpool docks amounted in 1843 to 213,000 tons; while now it has risen to 450,000 tons, supplemented by another 150,000 tons from the other docks on the river, but disposed of elsewhere. According to the estimate above quoted of the Marine Surveyor, this total annual amount is more than ten times that of the accumulation which is due to the average annual erosion of the low cliffs bordering the entire of the tidal portion of the river.

Mr. Lyster is gradually introducing a new mode of dealing with these dredgings from the Liverpool docks, by conveying them in steam-scows out to sea, and depositing them at a spot on the seaward face of the Great Burbo Bank. During the last six months of 1874, owing to want of vessels, only about 40,000 tons, or about 300 tons per tide, were thus disposed of. When, however, this method is in full operation, it cannot fail to be beneficial to the condition of the river and of the sea channels, since it will remove a large quantity of detritus, which Nature itself, making use of the docks as a depositing tank, collects there without expense; and by this plan it is disposed of at a spot where, most probably, but little of it will find its way back again to the injury of the sea channels.

Many different statements have been made, and facts adduced, as to the action of the tidal current in the river Mersey, in its flow and ebb respectively, in transporting the sandy materials, and in the subsequent formation of the different banks in the river and in

its estuary. Captain Denham, in his Paper to the British Association before referred to, considered the annual deposit of mud in the bay to amount to 11,700,000 cubic yards; while the present Marine Surveyor, Captain Hills, after eighteen years' experience and numerous experiments, has found the proportions of silt to vary with different conditions of tides, winds, weather, and situation, so that he considers it impossible as yet to approximate to any precise statement on the subject.

Comparison of the Changes in the Estuary.

A brief inspection of the series of charts of Liverpool Bay, extending from 1689 to the present time (Plate 6), will suffice to show, first, that at low water a large expanse of sandbanks is exposed, which in course of time alter much in position; and, secondly, that the inlet and outlet of the tidal water to and from the river has always been by two distinct channels, the northern, or Crosby one, along the Lancashire coast, and the southern, or Rock Channel, skirting the Cheshire shore. Into these two heads, therefore—first, the sands, and, second, the channels—does the comparison of the changes in the estuary naturally divide itself.

Of the various charts, the earliest record, that by Captain Grenville Collins in 1689, must be set aside; as it is merely a sketch, sufficient to give an idea as to the direction of the channels and the whereabouts of the sandbanks, but not such as to afford reliable information respecting them. The chart by Fearon and Eyes in 1736 must form the commencement of the series; to be followed by that of Thomas, in 1813. The maps published in the interval, by John Eyes, Burdett, Laurie and Whittle, and by Steel, are hardly of such a nature as to afford, for various reasons, information sufficiently accurate for the purposes of the comparison here contemplated. Thomas's survey of 1813, undertaken at the request of the Lords of the Admiralty, is exact as far as it goes, and affords complete information as to the channels; but with regard to the sandbanks (particularly the Great Burbo, only partially surveyed) it leaves much to be desired. It is understood that Mr. Giles, after completing his survey of the river in 1821, made one of the estuary for the Corporation of Liverpool; but of this the Author has no information. It was in 1835 that Lieutenant Denham commenced that series of periodical surveys of the estuary, which have been continued by his successors, and which for some

time back have been made annually. These have all been conducted with the utmost accuracy; and the charts resulting from them, having all been published on the same scale, afford the basis of a complete comparison. Of this series it has been thought advisable to select, subsequent to that of 1835, those of 1840, 1846, 1852, 1857, 1866, 1871, and 1875.

There may be said therefore to exist for the Mersey estuary two distinct recording periods: an early one, 1689–1835, during which merely the principal changes which have taken place may be roughly traced and noted; the other from 1835 to 1875, throughout which the different phases of each great change have been most carefully noted, with all the accuracy and the improvements of modern science.

At the outset of the inquiry it will be necessary to draw attention to the uncertain accuracy of the earlier charts, arising not merely from the paucity of their information, but chiefly from the doubt as to the exact low-water level referred to in them. Even in the modern charts the datum of "low-water ordinary spring tides," although in general use, is liable to various interpretations.

The datum for the last fifteen years for all charts of Liverpool Bay is 10 feet below the Old Dock sill: the low water of a tide rising 21 feet above the Old Dock sill, which, as already stated, is the typical equinoctial spring tide; and few tides in the course of the year exceed it in range. This datum, however, is considered by the present Marine Surveyor, after a careful examination of levels and soundings, to be practically identical with that adopted by his predecessors; who, in desiring, for the practical purposes of navigation, to be on "the safe side" by showing too little rather than too much water, had deviated from the customary tidal establishment of Admiralty surveyors—low water of ordinary springs, 8 feet 8 inches below the Old Dock sill. This uncertainty in the exact low-water level sometimes renders the information hereafter appended little more than a surmise, especially as to the area of the sands in the earlier epochs.

Sandbanks in Liverpool Bay.

A brief inspection of the chart will show that the sandbanks consist of those attached to the mainland along the Lancashire and the Cheshire coasts, and of those detached from it, viz., the Great Burbo (filling in the space between the northern and the southern channels), the East Hoyle (forming the western boundary of Liver-

pool Bay and dividing it from the estuary of the Dee), and a few small banks at the northern extremity of the bay separating it from the tidal waters of the Ribble. These last have sometimes been attached to, and sometimes isolated from, the mainland, but more generally the latter; they have been known under the various names of the "Mad Wharf," "Formby," "Taylors'," and "Jordan's" Banks, &c. A comparative table, C, in the Appendix, extending over nearly one hundred and fifty years, of the sands in Liverpool Bay, outside the present docks, shows that the total area has been pretty constantly the same, though perhaps slightly on the increase; and that the variation in the different banks has been but an interchange of deposit, carried from one part of the bay to another according to the dominant direction of the tidal current. In 1856 Mr. Joseph Boult, in his Report to the British Association for the Advancement of Science, "Upon the Changes in Sea Channels of the Mersey, &c.," presented some elaborate tables showing, among other things, the comparative volume of these sandbanks between 1837 and 1854. The result shows in the entire volume a slight increase at the later period, in a somewhat similar ratio to the augmentation of the total area in the annexed table.

Some of the most remarkable phenomena disclosed by the mutations of these sands are: the silting up of the Hoylake (due, it is generally supposed, to the extensive reclamations of the river Dee near to Queen's Ferry); parts of which are now dry at low water spring tide, to a height of 16 feet, where in 1736 there existed 35 feet of water; giving an accumulation of sand at that spot of more than 50 feet. Also—in the piercing of the East Hoyle Bank by Helbre Swash—there is now 60 feet of water, where formerly the bank dried 20 feet above low water, giving a variation at that point of 80 feet in depth of the sandbank. Again, the oscillations in the site of the "Mad Wharf," the "Jordan's," and the "Taylors'" Bank, caused by the development of the different outlets to the northern channel, have disclosed as much as 20 feet of difference in the elevation of those banks. In order to ascertain accurately whether the sands attached to the mainland had encroached upon it, or *vice versâ*, a fresh triangulation of the shore line was made in 1857 by the present Marine Surveyor, and compared with that of 1835, Lieutenant Denham's first survey. It was then found that on the Cheshire shore the sea had encroached upon the land to the extent, at the Red Stones, near Hoylake, of 160 yards, diminishing to 80 yards at the western end of the Leasowe embankment. On the Lancashire shore the encroachments of either element nearly counterbalanced the other; north

of Formby Point the land had gained the day, while to the south of it the sea had been slightly the victor.

Channels and Entrances to the River Mersey.

1. *Southern or Rock Channel, and its outlets.*—Branching abruptly at right angles from the main stream of the river Mersey round the Rock Lighthouse, where formerly stood the Rock Perch, this channel hugs the line of the Wirral peninsula in a westward direction, running between the Mock Beggar Wharf and the Great Burbo Bank (here called the "Brazil" Bank, the "North" Bank, and the "North Spit") up to a point on the main shore called the "Dove Spit." The main channel here is deflected to the north-westward through an angle generally of about 45°, and, under the name of the "Horse" Channel, passes on to the open sea, skirting in its progress the eastern edge of the East Hoyle Bank. At the junction of the Horse and the Rock Channels there exists, though now almost obliterated at low water, a passage through what was known as the "Hoylake" into the river Dee, near to Helbre Island. This passage through Hoylake in 1689 appeared with an average width of $\frac{3}{4}$ mile, and a depth of from 5 to 7 fathoms In 1736 it was narrower and with a depth of only from 2 to 5 fathoms. In 1813 this channel had further narrowed to an average of 200 yards wide, and a reduced depth of $1\frac{1}{2}$ to 3 fathoms. In 1835 it had become a tortuous channel from 50 to 100 yards wide, with a ridge, dry at low water, not far from its eastern end, and a pool opposite the village of Hoylake about 1,000 yards long with a maximum depth of 20 feet, the remainder of the channel averaging only 5 to 7 feet deep. By 1840 the eastern extremity had silted up for a length of nearly 1,000 yards, showing 2 to 3 feet at low water, the remainder of the channel consisting of two long pools, the one opposite Hoylake village being the deeper. In 1846, at low water there only remained of this channel a small pool on the site of the "Hoylake" about 700 yards long and 40 to 60 yards broad, with 6 to 10 feet of water in it; the sand in some parts of the site of the former channel being there as much as 9 feet above low water, although in general it averaged 4 to 5 feet high. In 1852 a small pool, with 2 to 6 feet of water in it, was all the trace remaining of the "Hoylake;" some parts of the old channel having by that time silted up as high as 16 feet above low water. This condition of things has continued with but little change to the present day, the position and size of the pool altering somewhat from year to year. As already stated, the silting up of

this approach to the river Mersey, much used at one time by coasting vessels, is set down to the land reclamations on the river Dee, and not to any tidal action in the Mersey or its estuary.

Reverting to the main Rock Channel: so slight have been the alterations in it during late years, that the following brief description of its low-water features applies almost equally to any period since 1835. From the Mersey a narrow and quickly contracting mouth, also shoaling rapidly, passes through a narrow gut 30 to 60 yards wide over a rocky sandstone ledge, with not more than from 1 foot to 3 feet of water upon it, which leads through a throat gradually widening and deepening into the Rock Channel proper; the entire length being about 1,000 yards. This main channel is about 4,000 yards up to the Dove Spit, with a breadth of 200 to 300 yards at either end, and an average of 600 yards in the middle; the general depth on the leading navigable line ranging from 14 to 20 feet. At the Dove Spit it is taken up by the Horse Channel, which deepens rapidly, especially after rounding the Spencer's Spit and the projecting elbow of the East Hoyle Bank. The alterations since 1835 have consisted chiefly in variations in the projecting edge of the banks at either side of the Rock Gut, rendering its navigation more tortuous at one time than at another, and of temporary advances of the line of the banks at the north side of the Rock Channel. Of late years, also, the junction of this channel with the "Horse" has been much inconvenienced, and the navigation rendered less direct, by the encroachments of the Spencer's Spit; while the "Horse" itself has been incommoded by the eastward progression of the East Hoyle Bank. In 1736 the site of the present Rock Channel was divided diagonally by a long tongue-like peninsula of sandbank, called Mock Beggar Wharf and the Beggar's Patch, attached to the mainland not far from the Rock Perch, and extending as far as the Horse Channel. The direct entrance hence to the Mersey is along Spencer's Gut and Wallasey Hole, on the northern side of the above-named bank. By 1813 this long strip of bank was almost entirely removed, and the Rock Channel had assumed its present position, excepting, however, a small isolated bank in the centre of the narrow gut by the Rock Perch.

From this brief historical sketch of the southern channel to the Mersey, it may be seen that the general impression as to its gradual and constant deterioration is hardly borne out by facts, except so far as regards the Hoylake branch into the Dee; and for the loss of this inlet, much felt as it may be by coasters, the Mersey cannot be blamed.

2. *Northern or Crosby Channel, and its outlets.*—This channel, practically the continuation of the river, is broad, straight, and follows a northerly direction along the Lancashire shore for between 3 and 4 miles to a point where it is deflected to the north-westward; it is also about this point, or a little beyond it, that one of its outlets (the "Old Formby") branches off across the sands, and then, keeping in a northerly direction close in shore, opens for itself a path into the tidal stream of the Ribble. The main channel itself continues in its deflected course for 2 or 3 miles farther, throwing off, meanwhile, to the westward one or more secondary, and sometimes discarded, outlets. At the extremity of this second portion of the main channel, either in continuation of it, but more generally somewhat deflected to the westward, is its principal or sea-going outlet, continuing for a mile or more, and leading into the open sea over a shallow bar. At the elbow or bend in the main channel there has been placed for many years past the Crosby Lightship; and at its seaward extremity the Formby Lightship.

Thus the northern approach to Liverpool consists of a wide channel with a bend in it, and of several outlets or entrances to it. These entrances, as well as the seaward part of the main channel, have been constantly subject to great variations, in consequence of the shiftiness of the sandbanks. In Table D, in the Appendix, describing the low-water spring-tide features, an endeavour has been made to epitomise the principal of these changes, so as to afford at one view the elements of a chronological comparison.

The portion of the Crosby Channel from the Rock Lighthouse to the Crosby Lightship has at times, as may be seen from the table, varied much as to length, influenced, no doubt, by the angle of deflection of the tidal current of its principal outlet—longest when that outlet is in direct continuation, or nearly so, of its own deflected portion; shortest when the angle of divergence of the outlet from the main stream is considerable. In other respects this first portion of the main channel has generally presented much the same features; which may be briefly stated in the following terms. A broad, straight, navigable passage, from 700 to 800 yards wide on an average, with a depth ranging from 45 to 30 feet on its leading line. Unless it is that within the last few years an isolated bank has been gradually forming on the south side of it, not far from the Great Burbo, and at about halfway in the length of its course; the effect being to contract at that point the navigable width to a little over 500 yards. This is similar to what was recorded in 1735 and again in 1767, when the channel was con-

tracted in about this part, not by an isolated bank, but by the projection of the Great Burbo Bank, and a part of the sands of the mainland near Crosby Point; afterwards developing into a long tapered peninsula of sand, called the "Middle Patch," and extending for some distance northward. Near to the bend in the main channel at the Crosby Lightship is first felt the effect of the variations in the banks; the north-east elbow of the Great Burbo pressing it on the one side, while the "Taylors'" and the "Jordan's" confine it on the other. All these banks have, of late years, been subject to considerable though gradual alterations in form.

The second or deflected portion of the main channel is inferior to the first part in width, 500 to 600 yards being the average, and even less towards its seaward end near the Formby Lightship; while its depth generally ranges from 35 to 25 feet on the leading line. The navigation of this portion of the northern channel is subject to periodical inconvenience arising from isolated banks, such as the "West Middle" and the "Little Burbo," cropping up and altering in position from year to year.

The outlets to this northern channel have always been two in number, each distinct in character; a principal or sea-going one, and a secondary or coasting one. It may appear erroneous to speak of only one principal or sea-going outlet, since at certain epochs two appear to have simultaneously existed near together; as, for instance, between 1840 and 1870, when the "Victoria" and the "Queen's" channels were almost side by side. A close inspection of Table D will, however, show that only one of these existed at a time in full vigour; the other being in process of formation, and, on arriving at maturity, supplanted its predecessor, which soon fell away and became gradually extinguished.

Of these principal or sea-going outlets, the records extant show that seven at least have existed, viz., in 1689, the "Formby," in a position about similar to that now occupied by the "Queen's." In 1736 another "Formby," in a position considerably to the northward of the one just referred to; in the charts of 1755 and 1767 this may still be traced, but with an angle of deflection increasing in a westerly direction; and even in 1813 there were still traces of it, its angle of deflection being still further augmented. In 1755 a "New" channel, with a considerable angle of deviation, augmented in 1767, of which no later records appear to exist. In 1813 a "South" channel, in a northerly site, however, as regards the general position of these main outlets, almost extending into the district of the secondary ones; its angle of deflection was considerable, and there seem to be no further traces of it. In 1835

another "New" channel (Denham's), in a southerly position, and considerably deflected; by 1840 this outlet was closed, its angle of deflection having increased in the interval. In 1840 the "Victoria" was first recognised as a navigable channel, though traces had appeared before; its angle of deflection was considerable; this outlet appears upon all the succeeding charts till 1870, its deflection increasing, and the outlet deteriorating in value with each year. In 1854 the present channel, the "Queen's," appeared as a navigable outlet.

Of the seven outlets, four occur previous to 1835, and a few isolated facts as to their existence are all the records that remain of them. It is, therefore, as to three only that there are any accurate data wherewith to form a connected history; of these the "New" and the "Victoria" alone have run their full course, and the earlier phases of the former are shrouded in obscurity. There may, however, be noted as features common to all these outlets, first, that the position of each has always, from the date of its first appearance, progressed gradually in a westerly direction, and almost invariably with the angle of deflection from the main channel proportionately increasing; secondly, that each has always had a bar at its outer extremity, gradually advancing seawards as the outlet deteriorated; thirdly, that the depth of water on that bar has gradually increased to from 11 to 12 feet, after which it has, as a rule, steadily diminished, and the outlet proportionately deteriorated. As to the duration or life of each outlet as a navigable channel, there are as yet hardly sufficient data whence to deduce any substantial theory. Plate 3, representing the position and angle of deviation of the outlets at certain periods, will afford some idea of the magnitude of the changes in direction which have taken place.

The "New" Channel (Denham's), with its beginnings unknown, was first discovered in 1833, and lasted till 1841, only eight years; it had a considerable angle of deflection. The "Victoria," with a navigable life extending from 1838 to 1858, a period of twenty years, had an angle of deflection less than the preceding. While the "Queen's," still existing, though of late somewhat impaired, attained its majority in 1857; so far, after nearly twenty years' good service, there have been no signs of its successor. The first traces of this channel appeared in 1854. There is one peculiarity attached to this outlet which does not appear to have occurred with any other. For some years at the commencement its angle of deflection from the main channel was westerly; by a gradual easterly progression it was brought into direct continu-

ation of that channel, where it remained for some years; of late, however, it has shown a tendency to deviate to the east of direct continuation of the main channel. The comparatively slight, and, moreover, oscillating, deflection of this outlet, which has never exceeded 20° from the direction of the main channel, ought to insure for it a longer existence than its predecessors, the "Victoria" and the "New," in both of which the deflection of the outward tidal stream was more abrupt.

There always appears to have been a secondary or coasting outlet along the Lancashire coast, creeping between the mainland and that projecting ridge of sandbanks dividing the estuaries of the Mersey and of the Ribble. It presented features somewhat similar to (the now silted up) "Hoylake," on the Cheshire coast. The site of this inshore outlet has been always pretty much the same; opening, as already mentioned, from the main northern channel near to its elbow or bend, it found its way in a north-easterly direction, with a more or less tortuous and intricate course, across a ridge of sandbanks, generally with a minimum of 3 to 5 feet of water, into a deeper pool which ran almost parallel to the first portion of the main channel; it then continued northwards, and opened by a rather abrupt turn to the westward into the deep water of the Irish Sea. This seems generally to have been the low-water feature of this outlet. It was almost always known as the "Old Formby" Channel; sometimes, however, it was called the "Inshore deep." Its distinguishing features may be thus briefly stated—the dividing bar or ridge between the Crosby Channel and the Formby Pool, and the considerable westward angle of deflection at the mouth of the outlet. This ridge was particularly subject to variation; indeed in 1852 it had augmented so much as to present 2 to 3 feet of sand dry at low water, and thus to completely close the channel. This circumstance may perhaps be somewhat accounted for by the excellence at that time of both the "Victoria" and the "Zebra" channels, and the proportionably diminished necessity for a third outlet. At the present time, while the "Queen's" is in a somewhat deteriorated condition (though improving for the last few years), the "Old Formby" is in a particularly good one.

The result of the operations of Nature described in this Paper may be thus briefly summarised.

1. That in the river Mersey the deterioration in the upper estuary and the higher tidal reaches has been but slight; while in the contracted channel between Liverpool and Birkenhead the

condition of the tideway, as curtailed by the formation of the Liverpool Docks, is in a better condition than before their construction, though at certain points, such as at Pluckington Bank, some deterioration may have taken place.

2. That in the estuary, of the outlets (originally four in number, three coasting and one sea-going) one, the "Hoylake," has been practically lost, through causes foreign however to the Mersey. But that the remainder, though subject to fluctuations in their effectiveness, and at the present time somewhat deteriorated, are in a better condition than at some previous epochs. While the sandbanks, though subject to considerable alterations in position, have apparently increased but slightly during the last one hundred and fifty years.

Tides in the River Mersey.

Before concluding this notice of the changes in the river Mersey, it may be appropriate to say a few words respecting the tides in the river, seeing the important, if not paramount, part which they have played in causing those changes.

The first tidal observations at Liverpool, of which there is any record, were those noting the high water of each tide, together with other meteorological facts, by Mr. W. Hutchinson in 1766, the then Dockmaster; they were continued by him till 1796, when he retired from office. Subsequently, similar observations were taken at different periods. But it was not until the latter end of 1853 that any systematic observations, continuing through the entire duration of each tide, were commenced to be taken, by means of the self-recording apparatus at the George's Pier Head at Liverpool. In 1847 there was placed in position the first of the floating landing-stages, the George's, and it was connected with the shore by two bridges; the entire structure rising and falling with the tide. When it was proposed to establish the self-registering tidal gauge, advantage was taken of this facility to follow the movement of the tide by attaching to one of the bridges, the southern one, at about 6 feet from its shore extremity, one end of a small chain; the other being connected with the recording apparatus, and communicating to it the variations in level of that point of the bridge, and consequently also of the tidal water. These were recorded by a pencil on a diagram sheet wound round a drum, driven by clockwork; and thus a continuous tidal curve was formed. Another self-registering gauge was set up at Helbre Island, off the mouth of the Dee; the level of the tide there being found to

be practically identical with its condition at the bar off the mouth of the principal channel.

By the courtesy of the Marine Surveyor, the Author has been allowed to inspect the registers of the George's Pier Head gauge. From them has been prepared a table of annual means, of high water, of low water, of tidal range, and of half-tide level, for the twenty years from 1854 to 1873; which was communicated to the Mechanical Section of the British Association at the Bristol meeting.[1] The result shows that a progressive rise has taken place, though not a regular one, in the level of the tide, and also a slight augmentation in its range, extending throughout the entire period, with the marked exception of the last year, 1873, where the results arrived at are totally different from those of its immediate predecessors, and similar to the years at the commencement of the series. In connection with this year, it may cursorily be remarked, that it forms the commencement of a second lunar cycle in the series; the preceding nineteen being a complete lunation.[2]

In order to give a fuller idea as to the action of the tides in the Mersey, annexed are the diagrams of the tidal lines of the river (Plate 7), taken in the spring of 1874; one at the equinoctial spring tide (21 feet above Old Dock sill), the other at the following equinoctial neap (10 feet above Old Dock sill). They indicate the action of the tide from the "Bar" to Warrington Bridge; *i.e.*, throughout nearly its entire establishment. The diagrams fairly represent the typical greatest and smallest tides of the Mersey; as the actual tides on the days selected were but little influenced by wind or other meteorological causes. The heights at the "Bar" and at the "George's Pier, Liverpool," are taken from

[1] *Vide* "Report of the British Association for the Advancement of Science, 1875," p. 164, and Appendix, Table E.

[2] From the records of the tidal observations of the late Mr. Hutchinson, in the Lyceum Library, Liverpool, are given the annual means of high water for the years 1768 to 1773; and in the table annexed they are compared with those of 1868 to 1873; the result being to confirm the remark as to the years 1854 to 1873, viz., that a lifting has taken place in the mean level of high water.

TABLE of ANNUAL MEANS of HIGH WATER at LIVERPOOL, above Old Dock Sill.

	Feet above Old Dock Sill.				Feet above Old Dock Sill.		
1768	15·51	Mean of 6 years	15·66	1868	16·45	Mean of 6 years	15·86
1769	15·36			1869	16·12		
1770	15·51			1870	15·82		
1771	15·60			1871	15·71		
1772	15·75			1872	16·23		
1773	15·81			1873	15·43		

the curves of the self-registering gauges at Helbre Island and at the George's Pier: the remainder are the result of observations taken every quarter of an hour under the direction of the Author.

The subject of the tides of the Mersey is, however, one that ought not to be considered apart from the other meteorological phenomena which were occurring simultaneously. Interesting and important as the question is to engineers, it is far too extensive to be entered upon in this Paper.

In conclusion, the Author must express his sincere thanks to those gentlemen who have kindly placed at his disposal valuable information, more especially the Marine Surveyor of the Mersey Docks and Harbour Board, the Engineer of the same body, the Engineer of the Bridgewater Navigation Company, the late Mr. Thomas Webster, Q.C., F.R.S., and Mr. Joseph Boult, F.R.I.B.A. To Mr. Webster's publications, "On the Liverpool and Birkenhead Docks," and to Captain Graham H. Hill's "Essay on the Hydrography of the Mersey Estuary," as well as to his official reports to the Mersey Docks and Harbour Board, the Author is indebted for many interesting facts in the past history of the river Mersey and its estuary.

This Paper is accompanied by a series of diagrams, from which Plates 3, 4, 5, 6, and 7 have been compiled.

[APPENDIX.

APPENDIX.

TABLE A.—ABSTRACT of RESULTS of COMPARATIVE CROSS SECTIONS of RIVER MERSEY in Surveys of Messrs. Giles in 1820, Parks in 1861, and Hills in 1871.

Corresponding Areas in	Division I. (Rock Lighthouse to Dingle Point.)		Division II. (Dingle Point to Hale Head.)		Division III. (Hale Head to Warrington.)	
		Area in 1871. Sq. Yds.		Area in 1871. Sq. Yds.		Area in 1871. Sq. Yds.
	23 Cross Sections	694,600	14 Cross Sections	467,250	17 Cross Sections	50,615
1820 less abstractions, and 1861	14 Cross Sections increased . .	14,550	8 Cross Sections increased . .	13,450	11 Cross Sections decreased . .	7,980
	8 Cross Sections decreased . .	5,800	6 Cross Sections decreased . .	6,950	4 Cross Sections increased . .	190
	Giving a Gain of . . .	8,750 or 1·27%	Gain of .	6,500 or 0·14%	Loss of .	7,790 or 13·48%
1861 and 1871	13 Cross Sections decreased . .	17,700	14 Cross Sections decreased . .	40,950	9 Cross Sections increased . .	2,715
	10 Cross Sections increased . .	13,400	2 Cross Sections increased . .	3,150	7 Cross Sections decreased . .	2,075
	Giving a Loss of . . .	4,300 or 0·62%	Loss of .	37,800 or 7·48%	Gain of .	640 or 1·38%
1820 less abstractions, and 1871	13 Cross Sections increased . .	16,150	11 Cross Sections decreased . .	33,400	10 Cross Sections decreased . .	7,980
	10 Cross Sections decreased . .	11,700	2 Cross Sections increased . .	4,500	5 Cross Sections increased . .	890
	Giving a Gain of . . .	4,450 or 0·65%	Loss of .	28,900 or 5·86%	Loss of .	7,090 or 12·27%
Total of abstractions, 1820 to 1871— 44,950 Sq. Yds. of Sectional Area. On a total in 1820 of 732,150 of Sectional Area: Being 6% of the whole.			Total of abstractions, 1820 to 1871— 600 Sq. Yds. of Sectional Area. On a total of 496,750 Sq. Yds. of Sectional Area: Being 0·12 % of the whole.		Total of abstractions, 1820 to 1821— 150 Sq. Yds. of Sectional Area. On a total of 57,925 Sq. Yds. of Sectional Area: Being 0·26 % of the whole.	

TABLE B.—COMPARISON of the CUBICAL CONTENTS of the TIDEWAY of DIVISION I. (Rock Lighthouse to Dingle Point), taken from the same surveys.

	Cubic Yards.		Per Cent.
1820 actual	338,692,000	Abstractions .	5·87
" less Liverpool Docks abstractions . . .	318,790,000		
1861	322,465,000	Gain	1·15
1871	319,173,500	Loss	1·00
1820 actual	338,692,000	"	5·44
1871	319,173,500	Gain	0·43
1820 less Liverpool Docks abstractions . . .	318,790,000		

TABLE C.—COMPARATIVE TABLE of AREA of SAND in LIVERPOOL BAY above L. W. S. T. in the space Eastward of HELBRE SWASH, Southward of a line projected to the N.W. from FORMBY POINT, and outside of the present Liverpool Docks and of the Rock Lighthouse.

Date of Survey.	Attached to Mainland.			Detached Banks.				Total Area of Sands Exposed.
	Lancashire.	Cheshire.	Total.	Great Burbo.	Jordan's Taylors', &c.	East Hoyle.	Total.	
	Sq. Miles.	Sq. Miles.	Sq. Miles.	Sq. Miles.	Sq. Miles.	Sq. Miles.	Sq. Miles.	Sq. Miles.
1736	6·36	4·72	11·08	10·82	3·49	5·06	19·37	30·45
1813	7·38	4·28	11·66	9·57[1]	1·69	3·90	15·16[1]	26·82[1]
1835	9·11	3·66	12·77	9·77	1·31	4·53	15·61	28·38
1857	8·38	3·83	9·21	10·98	2·81	6·60	20·39	29·60
1871	7·72	3·58	11·30	10·50	3·84	6·01	20·35	31·65

[1] These figures can only be taken as approximate, as the sea face of the Great Burbo Bank was not surveyed by Thomas.

Table D.—Variations in the Outlets of the Northern Channel to the River Mersey.

Date of published chart.	Crosby Channel.			Outlet.		Total distance Rock Lighthouse to Bar or to Mouth.	Minimum depth of water.	Name of Outlet Mouth.	Remarks.
	Rock Light to Crosby Lightship.	Angle of Deflection.	Crosby Lightship to Formby Lightship.	Angle of Deflection.	Formby Lightship to Bar or Mouth.				
	Yards lineal.	°	Yards lineal.	°	Yards lineal.	Yards lineal.	Feet.		
1736	5,500	13 0	9,000 4,800	52 55	7,000 4,000	21,500 14,300	6 2 to 4	Formby. Swashway.	
1767	8,000	30	7,000	74 0	7,000 4,000	22,000 19,000	12 8	Formby. Inshore dp.	Behind the "Mad Wharf."
1813	11,150	0	3,500 4,000	50 68	4,000 3,000	18,650 18,150	9 6	South. Formby.	
1835	6,700	10 tortuous ..	6,000 9,000 ..	57 28 10 E.	4,400 3,500 ..	17,100 19,200 ..	12 5 3 to 4	New. Formby. Swashway.	Site of "Zebra."
1840	6,700	15 tortuous	5,900 6,000	28 12 E. 27	4,700 4,000 4,000	17,300 16,600 16,700	11 5 to 6 5 to 6	Victoria. Half-tide, Swashway. Old Formby.	Future "Zebra."
1846	7,000	15 tortuous	6,400 11,000	35 0 47	4,700 4,600 3,000	18,100 17,600 21,000	11 7 to 9 5 to 7	Victoria. Half-tide, Swashway. Old Formby.	
1852	9,000	18 cut off	4,700 6,000	45 0 47	4,500 4,200 4,000	18,200 17,900 19,000	11 8 dry 2	Victoria. Zebra. Old Formby.	Across Formby Bk. and Jordan Bk.
1857	9,500	24 tortuous	3,000 5,750 8,000	28 20 49	5,500 2,000 2,000	18,000 17,250 19,500	11 11 7 to 8	Victoria. Queen's. Old Formby.	2 bars to Victoria Chl. Through gut behind Jordan Bank.
1866	10,000	25 tortuous	2,500 5,000 8,000	29 20 49	5,000 3,000 1,000	17,500 18,000 19,000	7 12 7	Victoria. Queen's. Old Formby.	Wider and better.
1871	10,000	35 tortuous	5,500 7,500	0 48	3,200 1,500	18,700 19,000	10 7	Queen's. Old Formby.	Traces only of Victoria Channel.
1875	10,000	35 tortuous	5,500 7,800	0 49	3,300 4,000	18,800 21,800	10 6	Queen's. Formby.	

TABLE E.—RECORDS of TIDES in RIVER MERSEY at LIVERPOOL, taken by the SELF-REGISTERING TIDE-GAUGE at the GEORGE'S PIER HEAD, LIVERPOOL.

Date.	Mean H. W. above O. D. S.	Mean L. W. below O. D. S.	Mean tidal range.	Mean half-tide level above O. D. S.	Mean, 1854–1863.	Mean, 1854–1873.
	Feet.	Feet.	Feet.	Feet.		
1854	15·423	5·546	20·969	4·938		
1855	15·366	5·570	20·936	4·898		
1856	15·513	5·466	20·979	5·023		
1857	15·519	5·531	21·050	4·994		
1858	15·349	5·575	20·924	4·887		
Mean	15·434	5·538	20·973	4·948	Feet. H.W. (above O. D. S.) . 15·562 L. W. (below O. D. S.) . 5·567 Tidal range 21·129 Half-tide level (above O.D.S.) 5·011	
1859	15·661	5·477	21·138	5·107		
1860	15·573	5·556	21·129	5·126		
1861	15·638	5·438	21·076	5·100		
1862	15·777	5·551	21·328	5·113		
1863	15·779	5·958	21·758	4·920		
Mean	15·689	5·596	21·285	5·073		Feet. H. W. (above O. D. S.) . 15·757 L. W. (below O. D. S.) . 5·527 Tidal Range 21·283 Half-tide level (above O.D.S.) 5·124
					Mean 1864–1873.	
1864	15·743	5·923	21·666	4·910		
1865	15·848	5·980	21·828	4·934		
1866	16·041	5·708	21·749	5·166		
1867	16·150	5·443	21·593	5·353		
1868	16·445	5·139	21·584	5·653		
Mean	16·045	5·639	21·684	5·208	Feet. H. W. (above O. D. S.) . 15·953 L. W. (below O. D. S.) . 5·486 Tidal range 21·440 Half-tide level (above O.D.S.) 5·237	
1869	16·116	5·617	21·733	5·250		
1870	15·820	5·663	21·483	5·078		
1871	15·708	5·206	20·914	5·251		
1872	16·282	4·832	21·064	5·700		
1873	15·430	5·354	20·784	5·038		
Mean	15·861	5·334	21·196	5·265		

Datum :—Old Dock Sill (O. D. S.) at Liverpool.

[Admiral G. EVANS

Admiral GEORGE EVANS remarked, through the Secretary, that whilst giving the Author full credit for care and ability, he considered it his duty, as Acting Conservator of the River Mersey, to point out certain errors and omissions in the Paper, and to express regret that, before bringing it forward, Mr. Shoolbred had not communicated with him, on a subject to which so many years of his life had been devoted. It was stated in the Paper that, "though the Mersey Conservators are the legal guardians of the river, and alone are empowered to preserve it against encroachments, yet those who actually buoy and preserve the channels for navigation are the Mersey Docks and Harbour Board, &c."[1] This was true so far as it went; but it should have been stated that such operations could only be carried out with the sanction of the Mersey Conservancy Commissioners, with the exception of the operations of lighting and buoying outside the harbours, which were under the control of the Trinity Board.

It was also said that "it is satisfactory to notice that, after more than fifty years' experience, during which the requirements of commerce have been satisfied by yielding a considerable portion of its bed for docks, the former condition of the present tideway has not merely been maintained, but has been somewhat improved."[2] The cause of the improvement was not mentioned, although, as pointed out in many of his yearly reports, it was evidently due to the Conservancy Commissioners having, on his recommendation, insisted on the dock walls, on both sides of the river, being constructed on the hydraulic principle of the contracted vein.

Further, it was observed that "Mr. Lyster is gradually introducing a new mode of dealing with these dredgings from the Liverpool docks, by conveying them in steam-scows out to sea, and depositing them at a spot on the seaward face of the Great Burbo Bank. During the last six months of 1874, owing to want of vessels, only about 40,000 tons, or about 300 tons per tide, were thus disposed of."[3]

Now, so far from Mr. Lyster introducing this system of dealing with the dredgings, the Engineer to the Mersey Docks had, in the first instance, strongly opposed it, and it was only on Admiral Evans' urgent representation to the Dock Board of the injurious effect produced by these dredgings while deposited in the river, that a steam screw barge of 300 tons burden was built as an

[1] *Ante*, p. 22. [2] *Ante*, p. 29. [3] *Ante*, p. 33.

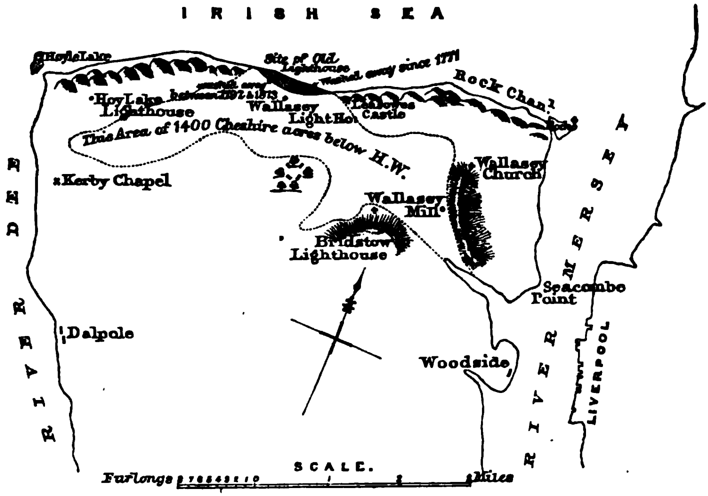
experiment. This answered so well that two more were added, making three steam mud-barges now actually at work, and five more of 500 tons each were about to be ordered, which would enable the whole of the dredgings to be taken out to sea. The quantity of dredgings taken out by the three steam barges between the 1st of January and the 31st of December, 1875, was 105,950 tons. The same process was, moreover, being carried on at the Garston Docks, where about 93,000 tons of dredgings had been taken out to sea by the steam hopper barges of the company. Since the adoption of this plan, the depth of water over the bar of the Queen's Channel had increased from 8 feet to 10 feet. It would also account for many of the improvements pointed out in the Paper, as the former mode of depositing dredgings would account for the silting in many places, particularly in the Rock Channel, for the deterioration of which it was stated that the "Mersey cannot be blamed," although it had been ascertained, by floats placed at the spot where all the dredgings used to be discharged, that the particles held in suspension in the waters of the river had been carried down the wrong channel.

Mr. Rawlinson, C.B., observed that, having been connected with the docks at Liverpool in former years, and knowing something of the channels and the character of the river, he was able to state that the practice at that period was to dredge the docks and discharge the material in the river outside. The basins were always scuttled, when the tide served, during spring tides. The material moved by the waters of the Mersey at that time was enormous, compared with which the amount of dredging mentioned by Admiral Evans was infinitesimal. The volume of water flowing in and out of the estuary between Liverpool and Wallasey, during a full spring tide, was not less than 500,000,000 tons; and if it carried in suspension 1 part in 1,000 parts only of sand and silt, not less than 1,000,000 tons of sand and silt would be moved in one full tide. One spring tide moved more solid material up and down the river than would be dredged out of the Liverpool Docks in a century; and it was therefore beyond comprehension why the Dock Trustees should be compelled to take the accumulation of the docks by steam barges outside a line of sandbanks. They were a rich body, and no one was interested in the Dock Trust but the ratepayers, so that perhaps it did not much matter; but he thought it was a waste of money to carry the dredgings out into the channels in the hope of benefiting the bed of the Mersey. The volume of water passing through the Black Rock Channel must be much more than sufficient to scour away the detritus deposited there.

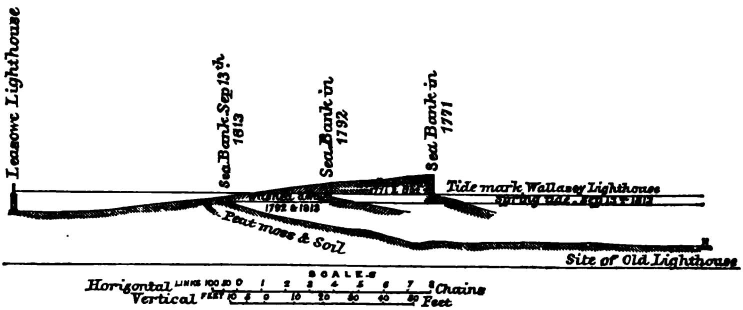
When Engineer to the Bridgewater Trust, he had charge of the river Mersey as far as that Trust extended. He had weekly soundings taken of the variations in the upper reaches of the river, and it would be nothing new to hydraulic engineers to be told, that no two weeks ever gave the same soundings. There was unceasing change in all tidal rivers and estuaries; a constant shifting of material from one point, and an accumulation at another, sometimes to an extraordinary extent. Pluckington Bank extended during neap tides as low down as the Prince's Dock; and, when he had charge of the landing-stages, he had stood upon the bank at six o'clock on one evening, it being hard and dry, and at six o'clock on the following evening there had been a depth of 16 feet of water at that point. The current had set in upon the face of the bank during the ebbing springs, and removed every bit of it. He was not prepared to say whether, if the Engineer had boldly faced the difficulty, and carried the dock wall out farther on to the bank, so as to bring the scour closer to the wall, it might not have been removed. There was a deep run along the Prince's Dock wall, so that there was no accumulation there interfering with the channel, but there was nevertheless some variation. Accumulations took place during neaps, which were removed during springs. He thought the Author had not read as fully as he might have done the early history of the river. It would be evident that if, in the Roman period, there was no knowledge of the river Mersey as now understood, some great change must have occurred since that time. There was an inland mere, or sea, having no direct outlet through the present channels. The great area of sandbanks, now extending from Southport to the Dee, was then a huge absorbent swamp, over which area most of the upper waters were lost. There was a careful itinerary, by Antoninus, of all the rivers from the Conway to the Ribble, and no mention was made in it of the river Mersey. The alterations that had taken place were therefore very great, as would be seen by comparing ancient maps with the Ordnance maps. The inland parishes in that part of Cheshire and Lancashire were large, while the coast parishes were mere fragments. Land no doubt existed seawards, when the parishes were first formed, which had since wasted away. There was a portion of the estuary embanked between the Mersey and the Dee at Leasowes; and along a line of bank of which he once had charge stumps of trees existed. It was a common saying that formerly that land had been so thick with forest trees that squirrels could jump from tree to tree for 20 miles inland. There was also a lighthouse at Leasowes, Fig. 1, that had been removed twice inland, the shore

having been wasted, since the first lighthouse was erected, to the extent of 700 feet. In sinking some wells there were records of similar formations at intervals of 20, 30, and even down to 90 feet below the present surface. In sinking a well at Wallasey, on the

FIG. 1.



WALLASEY LEASOWES, showing the Lands under the level of high-water mark.



CROSS SECTION of the SEA BANK and FORESHORE in the years 1771, 1792, and 1813.

margin of the Pool, an overlying stratum of boulder clay, 90 feet deep, had been found, resting upon a bed of sand, now quicksand, varying from 3 to 6 feet in depth, indicating a former coast line, and that the sand had been blown up, and had formed dunes upon the red-sandstone rock which was then submerged. It was interesting

to know the last geological changes in that locality, and, as far as he could gather from reading and from the study of maps, the last great change had been a downward one. Round the whole coast of England there were evidences of subsidence. There were the Goodwin Sands, which had been submerged within historic periods. There were also records of great areas of land which had been swamped from time to time; and from the Humber to Berwick-upon-Tweed the rivers were all upper branches of much larger rivers. It was further evident from geology that the Scotch mountains were amongst the oldest in the world, far older than the Himalayas, the Andes, or the Alps.

Mr. Brooks said engineers should not be thwarted in their efforts to improve rivers by the crude theories of those who, without practical knowledge, forbade all interference with them, and laid down laws in regard to river improvement and conservation. Engineers of undoubted talent had been daunted by the opposition that had been raised to works of great utility. No better example could be given than the case of the inclosure of a large portion of Jarrow Slake, to form the Tyne docks. It was always held that that abstraction of tidal water would prove injurious to the bar of the Tyne, and Mr. John Rennie objected to it because he had been led to believe by the nautical authorities that "at half tide, when Jarrow Slake was covering, the tide ran stronger over the bar." But he had proved that Jarrow Slake was only beginning to be covered at three-quarters flood over the bar; that at half tide it was dry, and that when Jarrow Slake was really filling, the tide on the bar had slackened considerably. So far from the inclosure doing harm, it was found to have done good, by causing an improvement in the navigable channel abreast of it, and by allowing a more free efflux and influx of the tide. The nautical authorities, in reference to the Mersey, held the same doctrine of strict conservation of the foreshore of the tidal receptacle, thus closing the door against any practical improvement of the channel and bar. The Mersey possessed enormous tidal power, and a fine natural drainage, yet it was in such a miserable condition that, with a rise of 30 feet at spring tides, it had only 9 feet of water on the bar, and at times only 7 feet. At the time of Captain Grenville Collins's survey, made between 1682 and 1687, there was a depth of 3 fathoms on the bar. His chart showed that the lower reach abreast of Liverpool formed part of a segment of a large circle, of which the seaward channel was the outer part, the radius being 10 nautical miles. The channel seaward of the rock was then called the Formby, and appeared to have been wider than the

pool abreast of Liverpool, the depth on the bar being 3 fathoms at low water, increasing gradually to 5 and 7 fathoms. At present there was no real channel for the ebbing current between the Burbo Bank and the Rock Point on the Cheshire shore after three-quarters ebb, and but for the resistance which the first quarter of the flood tide met with, owing to want of a free vent or discharge of the ebb previous to the commencement of the flood tide, there would have been no channel in existence abreast of the Cheshire shore, or westward of the Rock Point. That channel was only a flood tide swatchway made by the run of the early flood current, where it met less resistance than in the main channel, from the greater strength of the current of the ebb. The cause of the present bad condition of the river was the state of the inner part of the navigation, there being a mass of shoals above the pool, instead of a properly confined channel. If the channel had been carried up through the sands, gradually contracting from the width of the pool abreast of Liverpool, there would be a much greater rise at neap tides, and a better navigation. At the present time neap tides, when the wind was blowing out of the Mersey, were not even felt at Runcorn. Where river works were carried out judiciously, there was a much more powerful tidal column running up the river, and there was no such obstruction as that now existing on the bar. Notwithstanding the large volume of water from the backwater of the Mersey and its tributaries, due to the drainage of the country, the harbour was inferior to that of the Dart, in that the latter had 8 fathoms depth of water at its mouth at Dartmouth; and it was even inferior to the little river Medina between East and West Cowes, where the depth of water on the bar was 11 feet at low water of spring tides.

Mr. E. Leader Williams, Jun., remarked that in his opinion if ever the navigation of the Upper Mersey was to be improved it must be by means similar to those used for the reclamation of land in the Wash. The quicksands of the Upper Mersey were so deep that pile or stone work would fail. According to his experience of 'kid' work in the Severn, it was possible to keep packing on to the top, and to obtain a vertical settlement. The interests of the Port of Liverpool were so large, and the trade of the Upper Mersey was increasing so fast, that before many years a compromise must be arrived at. By some it had been thought that the Upper Mersey should be a mere tidal reservoir for the scouring of the bar, but there was a vast export and import trade, as well as a trade of 2 millions of tons carried on in inland craft, some of them of 200 tons burden, and drawing 8 feet of water, to be dealt with. If

works could be designed by which the Upper Mersey would be improved and the bar deepened, a great national work would be accomplished. A Bill was now in Parliament for the appointment of a Commission, to comprise the various interests concerned, somewhat similar to the Commissions connected with the Humber, the Clyde, the Tees, and other rivers. The Bridgewater Navigation Company would give up to that Commission the buoying and lighting, and would be glad to get rid of it, because it would relieve them of a serious responsibility. As the Channel shifted almost every tide, the question of buoying and lighting the Upper Mersey was too great for one interest to manage; and the matter certainly should not be in the hands of one company or trust, but under the control of a Commission representing the whole body of persons interested. The large middle portion of the Mersey, where the river widened out to a great extent, was in such a state that it was impossible to expect a good navigation. By confining the ebb and flow of the tide always in one direction, the same results might be expected as had followed in the case of other rivers. But without some such means the river would continue as at present, a mere waste of sandbanks with a constantly shifting channel. If fascine work were the proper means to be employed, the question was how high the banks should be carried, whether merely to quarter tide, or higher. It was certain that if the Channel was confined it would be deepened: then came the further question, how much of the tidal water could be safely abstracted without injuring the bar. Details such as those given by the Author would, better than anything else, enable a satisfactory result to be worked out.

Mr. A. Giles said, as the son of the man who made the survey of the Mersey in 1821, it was gratifying to hear that work spoken of as thoroughly accurate. He believed it was admitted that the work had been a standard one, and it was the first of the kind. The Author said the levels in the upper portion of the river, between Hale Head and Warrington, required some correction; for it was stated that the high-water spring tide generally flowed at Weston Point 1 foot above the high water at Liverpool. He believed it was admitted that the difference of tide from the Liverpool Dock sill to Weston Point, stated in his father's chart to be 1 foot, was about the same at the present time. A note on his father's plan stated that the difference between Weston Point and Warrington was only from 1 foot to 1 foot 6 inches. He thought that must be a clerical error, because if the tide rose 1 foot higher at Weston Point than at Liverpool, it was unreasonable to

suppose that it would not rise still higher at Warrington, which was more than double the distance. At the same time there were one or two reasons why there should be some alteration in the level of the tide at that point. It was stated in the Paper that Capt. Folkes had found the channel up to Runcorn so much improved, that vessels of 400 or 500 tons burden were now able to get up there; while twenty-five years ago no vessels over 250 tons could reach that place. It was evident, therefore, that the channel had been deepened, and consequently that a much larger flow of tidal water would get to the upper reaches of the river. That might account for some little difference in the rise of tide up to Warrington from what it had been fifty-five years ago. The Author further said, it was found, after careful observation, that the mean high water at Liverpool was higher than it used to be, consequently there was a higher range of tide than there was fifty-five years ago. With regard to the abstraction of land from the shores of the Mersey, referred to by Mr. Brooks as partly causing a decrease of depth at the bar, he was glad to find that, notwithstanding a decrease of area in the tidal estuary of the Mersey of about 5 per cent., the principal channel past Liverpool remained in about the same state as formerly, with one or two local exceptions. Thirty or forty years ago it was a commonly received opinion that the abstraction of the smallest quantity of tidal water from any estuary would to that extent affect the scour, and therefore damage the channel. That might be very good in theory, but it was not so in practice. There were many examples of rivers having been regulated and narrowed by banks nearly parallel that had increased the scour, and thereby deepened the channel. A large corner had been cut off Pluckington Bank since his father's survey, and he could only attribute that to the increased scour caused by the embanking of Wallasey Pool. If that embankment had been carried farther up, and the opposite quay advanced a little to the westward, he thought Pluckington Bank would be nearly got rid of. He could not conceive that the small quantity of dredging thrown into the Mersey could have any appreciable effect upon the channel or upon the bar, considering the vast volume of water going in and out; but it was unfortunate that there should be a depth of only from 9 feet to 12 feet at low water on the bar, with a range of tide of 30 feet. The Mersey Board might be rich, but he did not think it was rich enough to undertake the rectification of the channel sufficiently far out at sea to operate on the bar.

Mr. Redman said the Paper was an admirable exposition of the physical conditions upon which the Port of Liverpool, now the chief port in the empire, was dependent. There was, however, one condition not referred to, viz., the peculiar position of Liverpool in reference to the tide. It was situated between two nodes or neutral points of one of the three main waves surrounding the British Islands, one being situated at the north of Ireland, and the other at the southern extremity near Arklow and Wexford. The rise of ordinary spring tides at Liverpool was 26 feet, and of equinoctial spring tides 31 feet. In the North Channel, at the north of Ireland, the rise of spring tides was 4 feet, and it was the same at Arklow and Wexford. Thus an enormous body of water in the tidal wave (which struck the north and the south of Ireland almost simultaneously, there being a difference of only an hour and a half), was divided into two, and the two portions joined at Morecambe Bay, producing the extraordinary rise of tide at Liverpool. There was a 4-feet rise in the north and the south of Ireland, and assuming the mean level to be the same, there was an elevation of water of 10 feet, and a depression of low water of 10 feet; or assuming low water to be nearly plane, there was a depth of 20 feet of additional water heaped up in the north-east embayment of the north portion of the Irish Channel, and it was greedily sucked up by estuaries such as those of the Mersey and the Dee. Considering the enormous quantity of tidal water which passed above Liverpool, the condition of the entrance channels was certainly remarkable. The area given by the Author of 22,000 acres, with that rise of tide, if the river in the upper portion of its course were embanked, would give a total volume of water nearly equal to the volume of the Thames from Sheerness to Teddington, about 400,000,000 tons each tide. Taking the area of 22,000 acres by the vertical oscillation of 31 feet for equinoctial spring tides, and assuming the part shaded (Plate 3) to be of the same depth as the part indicated as deep water, it would yield 800,000,000 tons; but as the neap tides only reached halfway up the river, it was clear that the volume of water passing Liverpool was somewhat less than the volume of the Thames. The difference of high-water level between Liverpool and Runcorn, a distance of 25 miles, was 4 feet. The difference between Sheerness and London Bridge, a distance of 43 miles, was 3 feet 8 inches. With regard to the outfall channel, he had carefully studied the Admiralty charts, and the minimum depth appeared to be 2 fathoms. If it were now only 9 feet, that would show a decrease in depth of 3 feet of late years.

The same kind of action took place in the case of the outfall channels of the Thames: when one main channel silted up the other proportionately deepened. Queen's Channel, the old main channel on the southern side of the Thames, had gradually silted up, and Prince's Channel had deepened correspondingly. In the Bullock Channel, which had now broken through into the Black Deep, by giving the North Foreland a wide berth to the larboard, a vessel could pass in 40 feet of water up to Sheerness, and from thence in 30 feet to Gravesend. So that while Liverpool had the advantage of 6 feet increased oscillation of tide, the Thames had 28 feet additional depth at low water. There was great force in the observations that had been made as to the advisability of regulating the river channels. Liverpool, however, held its place of late years as the first port in the empire, its aggregate tonnage now exceeding that of London.

Mr. Shoolbred, in reply, said the Paper was of such length as to give him no opportunity of entering into the question referred to by Admiral Evans, as to the improvement in the first portion of the river being due to the principle of the hydraulic vein. He had thought it better to avoid entering into the question of the principles involved. The exertions of Admiral Evans in connection with the Mersey, extending over nearly half a century, were well known, and no idea had ever been entertained of endeavouring to detract from any merit due to him. If he had unwittingly said anything that would lead other persons to do so, he would readily withdraw it. Admiral Evans had stated that the system of depositing the dredgings at a distance outside the river was due to himself, and not to Mr. Lyster. He had distinctly mentioned in the Paper that Admiral Evans had on several occasions strongly objected to the disposal of the mud drainage in the river. It was the duty of the Conservator of the river to object to anything detrimental to its condition, but not actually to inaugurate or carry out improvements. He was no doubt the first to draw attention to the fact, but the introduction of the change was due to Mr. Lyster. The alteration in the disposal of the dredging did not take place till 1874; but most of the improvements to which attention had been drawn were shown to have taken place before the survey of 1871, and consequently previous to the new mode of dealing with the dredgings. The facts mentioned by Mr. Rawlinson as to the early condition of the locality were well known; but he had not thought it necessary to refer to mere tradition. Mr. Brooks mentioned that the neap tides only affected the river as far as Runcorn, but, in reality, save in some

exceptional cases, they extended to Fidler's Ferry, nearly 5 miles higher up the river. With reference to the statement of Mr. Giles as to the levels in the upper reaches, if his statement were correct, that a rise had taken place in the tidal waters, a large expanse of extra land in the upper reaches ought to be covered; but no increase had taken place. The inhabitants of the locality stated that the water rose practically to the same level as fifty years ago.

May 2, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

The following Candidates were balloted for and duly elected:—George Heaton Daglish, Ewing Matheson, and Sydney William Yockney, as Members; Captain Clayton Scudamore Beauchamp, R.E., Robert Bell Booth, Edward Kynaston Burstal, Stud. Inst. C.E., Henry Cook, John Joseph Davies, Elim Henry D'Avigdor, Philip Rickman Emmott, Richard William Henry Paget Higgs, Alexander Izat, Lieut.-Col. Alfred Stowell Jones, V.C., George Braithwaite Lloyd, John McLaren, Horace John Mannering, William Maylor, Patrick Walter Meik, Stud. Inst. C.E., James Richmond, Arthur Lewis Stride, Henry Thomas Simpson Ward, and Thomas Walter Woodhouse, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred Adam Fettiplace Blandy, Wells Hood, John Kyle, and John Steell, from the class of Associates to that of Members.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—John Charles Gill, John Henry Anderson Ivens, George Marston, Walter Smith, and Francis Aspinall Wythes.

No. 1,458.—"Fascine Work at the Outfalls of the Fen Rivers, and Reclamation of the Foreshore." By William Henry Wheeler, M. Inst. C.E.

The estuary of the Wash, on the east coast of England, receives the waters of the four rivers which drain the fens of Cambridgeshire and Lincolnshire. Of these the Ouse takes the rainfall from 2,960 square miles of high land and fens, the Nene from 1,132, the Witham from 1,050, and the Welland from 703 square miles. The waters of these four rivers, flowing from an area of 5,845 square miles of country, find their way to the sea through shifting sands which encumber the head of the estuary. The course of the various channels is continually changing, and their position shifting, owing to alterations in the wind or tidal and fresh-water currents. The strength of the ebb tide and land water is thus

exhausted in making fresh channels, instead of in keeping a deep and rapid course.

The Dutch engineers, who were first called in to advise as to the reclamation of the Fen lands, entirely ignored the outfalls of the rivers, and depended on schemes of internal drainage. By throwing up embankments on the sides of the rivers, cutting new drains, and erecting windmills to pump the water out of the drains, they succeeded in bringing into cultivation several thousand acres of land which had previously been swamps, tenanted only by wild fowl. As one swamp after another was reclaimed, the whole Fen country became split up into districts, with separate bodies of Commissioners acting independently of one another; each only solicitous for the welfare of their own territory, and jealous of spending money that might benefit their neighbours, or more especially the navigation of the rivers. The system commenced by the Dutch engineers has been continued to the present day. The various bodies of Commissioners, instead of taking a comprehensive view of the matter, and commencing the improvements at the outfall of the rivers, so as to facilitate the discharge of the waters to the sea, thus obtaining a better fall and general lowering of the waters throughout the main arteries of the drainage, have spent hundreds of thousands of pounds in works of interior drainage and the erection of steam pumps, one tithe of which, if applied in training the outfalls to deep water, would have obviated the necessity for mechanical means, and rendered the fens permanently safe.

Kinderley struggled hard in his own district to obtain an improvement in the outfall, and partially succeeded. Rennie used all the influence he possessed to the same end, but had to succumb to the selfish and narrow views of his employers, and only partially succeeded. The works he accomplished in the upper part of the outfall of the three great rivers were sufficient to show the immense advantages to be obtained from a straight channel properly confined, as compared with a wide and tortuous stream.

The straightening of the Ouse by the Eau Brink Cut, reduced the course of the water from a winding bed of upwards of $5\frac{1}{2}$ miles to a straight channel of 3 miles, and effected a fall in the low-water mark of from 8 feet to 9 feet. The works of the Norfolk Estuary Company, by making a straight cut of 2 miles through the marshes below the town of Lynn, and continuing the works through the sands by guide walls of fascine work, still further reduced the level of low water 3 feet, a gain of inestimable importance in a district where the fall in the main drains is often

not more than 4 inches in 1 mile. Kinderley's cut in the Nene and the new cut and training works of Rennie reduced the low-water level 10 feet in that river, and equally beneficial results followed similar, though more limited works, in the Witham and the Welland. These works, however, are only the commencement of what ought to be continued. As soon as the water leaves the trained channels it spreads out through several miles of shifting sands.

When, between the guide banks, there is upwards of 10 feet depth of water at low tide, below them there is only from 2 feet to 3 feet. By a continuation of the training work through the sands this bar would disappear, a fall of several feet would be gained, a natural drainage acquired in place of a mechanical lifting of the waters, and deep water would be provided for vessels at all states of the tide. A gradual accretion of land at the back of the guide walls would also take place, which ultimately could be inclosed and brought into cultivation.

A general outline of the position of the Fen rivers having now been given, it is proposed to describe in detail the plans adopted for training the channels of the rivers through the sand where already carried out, and the result which has ensued in the accretion and warping of land; the history of the large cuts being so well known, and having so often been described.

Fascine Work.

From the peculiar geological character of the Fen district, neither refuse slag from ironworks nor stone from quarries could be obtained within reasonable distance to form the guide banks, and the engineer had to rely on the natural resources of the country through which the rivers passed. At the suggestion of Mr. Beasley, an attempt was made to train the channel of the Welland with barrier banks made of fascines and clay This plan having been found to answer, it has been continued for all the training works in the Fen rivers.

The work is carried out in the following manner:—The line of the channel having been settled, operations are commenced on the convex side of the stream, so that the water may scour round the end of the jetty as it advances, and wash away the silt and sand through which the new channel is to be driven. Three barges are used, one containing faggots or fascines (locally called kids), the others clay. The barges are brought to the jetty at high water, two being moored in advance of the finished work and parallel with

the jetty, the other at the end of the two at right angles to them. At low water the men throw the faggots out of the boats on the water in the space left between the three barges, the faggots being placed transversely to the direction of the jetty, overlapping each other, and covering a space equal to the intended width of the base. Each layer of fascines is weighted with clay and gradually sinks, layer after layer being added until the fascine work rises above low water. The jetty is subsequently raised to a height equal to half-tide level. The batter generally given is at the rate of 6 inches to 1 foot. The greatest depth of water at low water in which jetties have been thus constructed is about 20 feet, the average depth being about 10 feet, and as the jetty rises 6 feet above low water, the total height of the fascine work is 16 feet, or, in extreme cases, 26 feet. The substratum of the estuary is clay, and on this the fascines find a firm resting place. When a good current is running, the silt or sand through which the channel is being driven, and which is from 3 to 4 feet above low water, is washed away for a space of 40 or 50 feet from the end of the jetty, and the fascines settle down at once on the bed. When the silt is not all removed it is gradually washed out from underneath the fascines, which settle down in a mass.

The fascines are made of thorns cut from the hedges, tied in bundles with tarred rope, the extreme length of each fascine being 6 feet, and the girth 3 feet. The branches, being small and tough, become interlaced. The silt brought up by the tides is rapidly deposited in and at the back of the work, and thus a solid embankment is formed of sufficient tenacity and strength to withstand the strongest tidal current, and so compact that, when necessary to remove any of the work, it can only be done by cutting the thorns out branch by branch.

The trained channel of the Witham is 200 feet wide; the flood tide runs up at the rate of about 5 miles an hour; the ebb, when heavy land freshes are running, moves at the rate of from 3 miles to 4 miles, with a depth of 10 feet or 11 feet, and, after the breakup of a frost, carries with it large blocks of ice. This stream has been diverted from its original course by jetties made simply with fascines and clay as described, a single course of stone bedded in clay being placed on the top to weight the fascine work and to prevent the upper layer being lifted by the tides or carried away by ice.

The channel of the Ouse is 500 feet wide, and 10 feet deep at low water; it is exposed to the effect of northerly gales. Guide walls, about 1 mile in length, of faggots, clay, and chalk, for car-

rying the water through the Vinegar Middle Sands, constructed about twenty years ago, have effectually answered their purpose, and withstood the efforts of the river to assume its old course, thus showing the practicability of training wide and deep rivers by this means.

In the Nene, the channel has been trained for 1¼ mile at its lower end with guide banks of fascines, clay, and chalk; the work having stood now for forty years.

The Welland has been trained through the sands for 1½ mile, the total length of the training walls being 2 miles 60 chains, and the cost, according to Mr. Walker's Report in 1838, £7,026.

In the Witham, a length of 3 miles of fascine work has been completed at intervals during the last thirty years, and the Author is now engaged in continuing the training at the lower end of the river. In all these cases the method of carrying on the work has been similar to that described, except that in the Ouse and the Nene a larger quantity of stone has been used, making the work more costly, and in the Welland marsh sods have sometimes been substituted for clay.

Cost of Fascine Work.

The cost of the work lately done in the Witham has been about 19*s.* per lineal foot, or 1*s.* 8*d.* per cubic yard. The average height of the pier is 16 feet. The base is 22 feet wide, and the top 13 feet. Each lineal foot takes about seventy faggots, which cost 14*s.* 6*d.* per hundred of six score delivered at any accessible place on the riverside. For getting and delivering the clay the men are paid 30*s.* a barge-load, containing about 30 tons, the clay being obtained from the foreshores at the lower part of the river. Conveying the faggots by boat from the place of delivery to the work, including loading and unloading, costs 4*s.* per hundred, the distance being about 5 miles, and the boats only able to navigate the river on the tide. One hundred faggots require 10 tons of clay. The cost of labour in building the jetty is 3*s.* per hundred. The whole cost may be summarised as follows:—

	£.	s.	d.
Fascines, per one hundred and twenty	0	14	6
Conveying by boat " "	0	4	0
Labour, laying, &c.	0	3	0
10 tons of clay at 1*s.*	0	10	0
Stone for top, ¼ ton at 6*s.*	0	1	6
Total per hundred kids	1	13	0

Or allowing seventy fascines to each lineal foot to the dimensions given above, makes the cost of the pier 19*s.* 3*d.* per lineal foot, or 1*s.* 8*d.* per cubic yard.

After the formation of the jetty, deposit rapidly takes place at the back, until the silt becomes as high as the top of the fascines. By fixing the channel in one place, and thus preventing the water continually turning over the sands, these jetties have been the means of warping up very large areas of land, which in course of time have been embanked and come under cultivation.

Accretion of Land.

The accretion of land in the Wash is slowly but continually taking place. Partly from the alluvial soil from the coasts of Lincolnshire and Yorkshire brought with the tides into the Wash, partly from the alluvion brought down the Fen rivers, and partly from the disturbance of the sands in the centre of the bay, there is always a large quantity of soil held in suspension in the water, which soil is deposited on the foreshores. As might be expected, the greatest increment is at the head of the bay, nearest to the mouth of the four rivers. Owing probably to the set of the tides and the prevalent winds, the increase is much greater on the western, or Lincolnshire coast, than on that of Norfolk. Mr. Gordon, in his report to the Admiralty on the evidence taken respecting the Lincolnshire Estuary scheme, gives the following estimate of the rate and the periods of inclosure. The quantity inclosed by the Romans in the first and second centuries is unknown. During the seventeenth century, banks were erected excluding the tide from an area of 35,000 acres. During the eighteenth century 19,000 acres were inclosed, and during the nineteenth, 6,000 acres. About 3,000 acres have been inclosed since that estimate was made. He states, further, that the advance on the Lincolnshire shore has been an average of ½ mile since the erection of the Roman banks. Of the total quantity inclosed since the time of the Romans, 8,000 acres belong to Marsh land in Norfolk along a frontage of 10 miles; 37,000 acres to South Holland, in Lincolnshire, off the coast of the parishes of Sutton, Gedney, Holbeach, and Moulton, with a frontage of 19 miles; and the rest to North Holland.

If not assisted by artificial means, the process of accretion is stationary after a certain distance from the shore. The oldest salt-marshes are about ½ mile in depth, beyond which there is nothing but bare sands. Directly the marsh is inclosed by a bank, and the water shut off, the accretion at once becomes rapid, and in the

course of a few months the sand is covered with warp; then a growth of samphire follows, succeeded by grass, and in a few years a marsh is formed outside the recent inclosure, which rapidly rises by the accession of warp, through which the grass grows, until for a foot or more in depth the soil is a mass of the finest warp, mixed with roots of grass and decayed vegetation. This process, repeated during several years, makes some of the most valuable and fertile soil in the country.

The cause of the accretion not extending beyond a certain point is easily explained. The tidal water, carrying matter in suspension, spreads over the foreshore up to the banks, and for the short time when there is a period of quiet, the matter in suspension is deposited. The silicious particles of silt and sand, having the heaviest specific gravity, are deposited first, the warp or loamy particles being carried back with the ebbing current. Gradually, as the marsh rises, the silt is deposited before the water reaches the banks, the warp alone being carried to the upper part and there deposited. As samphire and grass respectively grow, this process is hastened, the vegetation holding the warp and filtering it from the water as it recedes. To the deposit of this light flocculent matter, constituting the argillaceous portion of the suspended matter, a state of rest in the water is necessary, agitation keeping it in a state of suspension. After a certain breadth of marsh has been formed, generally on this coast about $\frac{1}{3}$ mile, the body of water flowing off the marsh on the recession of the tide becomes so great, as to form a current sufficiently strong to carry with it both the silicious and argillaceous particles held in suspension. After a time, from the action of the forward and retrograde motion of the wavelets of the ebbing tide, a marked and broken line or steep, from 1 foot to 2 feet in height, appears at the edge of the newly-formed marsh, up to which the neap tides reach, and beyond which the marsh ceases to grow. The existing marsh is then covered by spring tides, but continues to rise slowly until only covered by the few spring tides which rise above the average height.

Warp begins to take place at 12 feet above low water. Mean low water in the estuary is 7·32 feet below the Ordnance datum. Samphire commences to grow when the surface is just covered at neap tides, or from 14 to 15 feet above low water, and disappears when the level of the soil is about 16 feet above low water, or 2 feet above an ordinary neap tide; the samphire being gradually replaced by grass.

Newer and more recently-formed salt-marshes are about 18 feet above low water, and the old marshes 20½ feet. Much of the old

inclosed salt-marsh is higher than the land inside the Roman banks.

The following are the approximate levels at which the process of accretion takes place, compared with the Ordnance datum:—

	Feet.	
Mean low water	7·32	below.
Warp first deposited	5·50	above.
Samphire	6·68	„
Grass first appears	8·68	„
New marsh	10·68	„
Old high marsh	13·15	„
Ordinary neap tides	6·69	„
Ordinary spring tides	13·34	„
Mean high water	10·21	„

The period of time, during which the process is maturing, varies according to the situation of the marsh, and to the artificial means taken to assist the warping process. Silt foreshores, outside a newly-erected inclosure, become grass marsh in about ten years; but after this a period of twenty to twenty-five years ought to elapse before any inclosure takes place, during which time the marine vegetation and grass filter the finer particles of warp from the water, and the roots and decayed vegetation fill the soil with organic matter.

In 1837, when the training works of the Welland were commenced, a large area of the foreshore on the Moulton and Frampton shores was bare sand; in 1851 it was all grassed over, the Moulton marsh extending over 800 acres, and the Frampton over 300 acres. The latter was inclosed in 1864 and the former in 1875.

Under favourable circumstances the accretions have been very rapid. Thus, in the case of the river Ouse, when the Eau Brink Cut was made, the tides were allowed to flow into the bed of the old river, and at the end of fourteen years the upper portion was inclosed. Twenty years afterwards a second portion was taken in, and the remainder, making 900 acres altogether, within thirty years from the making of the cut. The lower area was inclosed too soon, and would have been much better land if warp for another ten years had been allowed to accumulate. The upper part, where the warp first settled, is now some of the richest and best pasture and arable land in the Fen district, and is let at a rental of £4 an acre. The circumstances here, however, were exceptional. The works of the Eau Brink Cut had such an effect in depressing the low-water level that the bottom of the old Bedford river, and all the side drains and ditches emptying into them, were run nearly dry, and when the winter rains came and

scoured them out, the alluvial deposit and vegetation in their bottom were carried down into the main stream, remaining there in suspension until brought back by the tides and deposited in the old channel during the quiet period at high water; thus not only was there an unusual quantity of matter in suspension, but the deposit was of the richest and most fertilising description. As a contrast to this, the first 1,300 acres of land, inclosed after the improvement of the river Nene, above the embankment of the Cross Keys Wash, being taken in too soon, was of the most indifferent kind, and not worth half the value of the land below the embankment, which was allowed a longer time to accrete. After the training works were completed in the Nene, about the year 1831, the land warped up rapidly, the process being assisted by the immense amount of soil removed from the new cut by scouring. Some of the land below the Cross Keys embankment warped up 7 feet, and became good grass marsh in twelve years. It was inclosed in 1842, and was sold five years afterwards for £80 an acre. Since the year 1831, upwards of 3,000 acres have been inclosed, which were let immediately after inclosure for from £2 to £3 an acre. Recent inclosures have been sold by the Commissioners at the rate of £60 an acre.

Encouraged by the large quantities of valuable land thus reclaimed, after the Eau Brink Cut and the training works in the Nene had been completed, Sir John Rennie devised gigantic schemes for inclosing all the foreshores lying along the Lincolnshire and Norfolk coasts, and bringing the four Fen rivers into one common outfall. These schemes were finally taken up by the Lincolnshire and the Norfolk Estuary Companies. Both obtained Parliamentary powers to carry out the works, but the Lincolnshire company was unable to raise the necessary capital. The Norfolk company, however, having secured a subsidy of £120,000 from the drainage and navigation interests in return for the improvements in the channel of the Ouse, obtained the necessary number of shareholders, but up to the present time, out of the 30,000 acres over which their power extended, only 647 acres of land of their own and 876 acres belonging to the frontagers have been inclosed, after an expenditure of more than £400,000. The remainder is still nearly all bare sands. There is only a small quantity of grass and samphire, the best of which will not be fit for inclosure for at least ten years, by which time, unless a fresh Act is obtained, the company's powers will have expired. Mr. Gordon, the Admiralty Inspector, pointed out that the quantity of warp brought up in suspension in the water could never be sufficient to accrete this vast

tract of land within any reasonable time, and that the experience of past times showed that the greater part of the suspended matter was all carried away from this part of the coast to Lincolnshire. A slow accretion is now going on between the new channel and the bed of the old river, but the great bulk of the 30,000 acres is no nearer being covered with soil than it was when the company first started operations.

Methods of Assisting Accretion.

On that part of the coast where the tides bring the alluvial deposit the process of warping has, in some places, been greatly assisted by rows of faggots placed parallel with the inclosure banks. These check the movement of the water and assist the deposit, and a striking difference in the height of the marshes may be seen on two adjoining estates, on one of which this process has been carried on, as compared with the other, where nothing has been done. The Norfolk Estuary Company has lately gone to great and unnecessary expense in attempts to make the foreshores accrete more rapidly, by placing parallel lines of piles and planks at right angles to the channel. These jetties are composed of fir piles 6 inches square, placed in duplicate at intervals of 6 feet; between them are boards, the tops of which are about 2 feet above the sands. The cost of these jetties is £6 per chain, and already 300 chains have been partly completed at a cost exceeding £600. The use of the boards has since been abandoned, and only single piles placed at intervals of 6 feet. As far as can be seen at present, no appreciable quantity of warp has been effected, and a much better result would have been derived from the use of faggots at one-tenth of the cost.

The accretion and growth of grass has also in some places been greatly assisted by what is locally termed 'inoculation,' or cutting sods off the marsh already formed, and laying them about singly on the silt; these become fixed, and the grass gradually spreads until the separate sods are united and the whole surface is grassed over.

After the marsh is covered with grass the surface becomes broken up by numerous creeks and 'pot-holes,' which are both expensive and difficult to deal with after inclosure. This in some cases has been obviated by a small expenditure of labour as the marsh is growing up, by cutting grips to lead the tidal water off, and thus forming straight channels, which ultimately serve as division ditches on the inclosed lands.

Crown Rights.

By a judicious expenditure of labour in placing fascines or straw ropes and sods on the bare sands, and by cutting watercourses as the marshes accrete, large tracts of valuable marsh might be added to the frontages of the various proprietors, but the uncertainty of the Crown rights delays the carrying out of works which otherwise might be attempted.

Over all sands and marshes covered by an ordinary high tide (by which is meant the average height of high water of all tides taken over a period of not less than one year), the Board of Trade claim an ownership on behalf of the Crown. Marshes fit for inclosure are above this level; but these are intersected by creeks and low places, which are covered at high water, and the Crown rights over these must be obtained before any inclosure can take place. The amounts paid for this are various. Generally it may be regarded as a nominal consideration for retaining the rights. Thus on the inclosure of the Kirton marshes in 1870, covering an area of 1,000 acres, the sum of £100 was paid as compensation for the creeks and low places below the level of high water, which covered an area of about 7 acres. For an adjoining marsh of 50 acres the sum of £50 was paid. For a marsh in Fishtoft of 130 acres, the Crown claims were settled by a payment of £60. For the Moulton marsh, containing 400 acres, the area of the creeks and low places below ordinary high water being 46 acres, and the rest of the marsh being 1 foot 6 inches to 3 feet above high water, the claim made by the Board of Trade was £100.

In these cases the amount is not of serious consideration, but in larger undertakings the value put on the sands is a complete bar to any scheme of improvement. Thus for a scheme of improvement for the outfall of the Witham, the promoters were anxious to buy up the Crown rights over the foreshores, extending over 1,000 acres of purely bare sand of no value, when the sum of £4,000 was demanded. Considering that even if this land warped up as rapidly as that on the adjoining coast, thirty years must elapse before it would be fit for inclosure, the compound interest at 5 per cent. would raise the cost of the land to over £16,000, in addition to which large sums would have had to be spent by the promoters in fascine work to make the land accrete. In the case of the Freiston Shore railway and reclamation scheme, the sum fixed for payment for Crown claim was equal to about £2 per acre. In the Norfolk Estuary works the compensation was fixed at 1 per cent. on the outlay. In the Nene Outfall

works the Crown receives one-sixth of all lands inclosed, provided such land was bare sands at the time the act for carrying out the works was obtained. For these sums, unless a special Act of Parliament has been obtained, the title thus given is extremely doubtful. The question arises, whether land which gradually accretes and grows to the frontage would not become the property of the frontager, and all right pass from the Crown. The foreshore is only the property of the Crown when it is below high water. As soon as it rises above this point, by the process of natural accretion, it becomes a part of, and belongs to the owner of, the foreshore to which it grows. The purchaser of the Crown rights over a tract of land, which had been bought for the purpose of reclaiming by accretion, might find that as the land accreted and grew, it was claimed by the frontager, and that the Crown conveyance was really worthless. Unless therefore under a special Act of Parliament, no improvement in causing the accretion and warping of land can be carried out, except by a frontager.

Value of the Salt-Marshes.

The foreshores, when they have grown into salt-marshes, are useful for the grazing of sheep, and let at from 5*s*. to 6*s*. an acre. The prospective advantages, however, make the value of the freehold greater than this rent would warrant. The sum of £20 an acre may be taken as a fair standard for the present value of a salt-marsh fit for inclosure. In the evidence given before the Norfolk Estuary Commissioners, the value of the marshes was put at £30, this being the price to be paid to the frontagers on a compulsory sale; but in the awards subsequently made for frontagers' marshes taken in by the company's embankment, the value of the marshes, before inclosure, was taken at from £18 to £20 an acre, and after inclosure at from £54 to £59 an acre.

Cost of Embanking.

The cost of embanking must of course depend on the depth of the marsh as compared with the length of the frontage, and special circumstances arising from situation make the banks either more or less costly. A fair average for an inclosure, with banks 10 feet in height, and slopes varying from 5 to 1 in the more exposed parts, to 3 to 1 where the bank is more sheltered, on the sea side, and 1½ to 1 on the land side, may be taken at £15 to £20 an acre, including the sluice and other necessary works. In addition to this from £3 to £4 an acre will be required for levelling and

ditching. The land is let directly after inclosure at from 40*s.* to 50*s.* an acre, the freehold being valued at from £50 to £60 an acre. Some of the best marshes after inclosure have realised £80 an acre, the proprietor taking all risk as to the maintenance and safety of the banks.

There is all along the coast of Lincolnshire a large tract of marsh and sandy foreshores, which, with the judicious outlay of a small sum of money, would become ripe for inclosure and add considerably to the value of the property of the owners of the land inside the sea banks on which it abuts. Considering the value of this accreted land when inclosed, it is a matter of regret, from a national point of view, when so much produce has to be imported from abroad, that more energy is not displayed in works of reclamation.

The communication is accompanied by diagrams, from which Plate 8 has been compiled.

[Mr. SHELFORD

Mr. Shelford said fascine work was generally used in the Fen rivers, and in rivers of a similar character, for the purpose of repairing any slips or bad places in the banks. It was important in such cases to give immediate attention, to prevent disastrous consequences, such as the submergence of large tracts of land. Ordinary fascine work was made of faggots, 4 feet in length and 3 feet in girth, laid in a sort of mattress, overlapping each other, covered with layers of clay 6 inches in thickness, then another layer of faggots, and so on, fastened down by stakes 6 feet in length, with pegs at the top, forming a compact mass. The slope of the work when finished should be 1 to 1. That kind of work had many advantages; amongst others it was exceedingly cheap, only 1*s*. 8*d*. per cubic yard; it was also light, an important point, as the foundation was usually bad. It acted as a revetment or retaining wall, and required no drainage, the faggots permitting the water to pass from it. It also presented a surface to the current with plenty of friction. That was an advantage not perhaps apparent to all, but those acquainted with hydraulic engineering would agree, that the gravity of the silt and the velocity of the current in contact with it were forces that were nicely balanced, and that a trifling interference with them would be productive of serious consequences. He remembered the case of a canal that scoured on one side but not on the other, and the engineer, thinking to repair it in a substantial manner, built a good clean wall; but, to his astonishment, as soon as it was finished the other side scoured, and he found the velocity of the stream so increased that he had to build another wall on the opposite side. Patch-work, at all events on rivers and canals like those in the Fens, should have a surface that would give plenty of friction for the stream. The patch-work would not only protect that part of the bank which it covered, but also, to some extent, by retarding the velocity of the current, the adjacent bank, and especially the one opposite to it. He was inclined to doubt the advisability of the more extended application of fascine work to the outfalls. That was chiefly a question of price. Although it had been successfully used in Holland, especially at the mouth of the Maas, yet in this country, in the neighbourhood of the Fen rivers, where there was a large quantity of chalk locally called 'clunch,' and where stone (oolite) could be obtained at a moderate price, it was a question whether, if the money were forthcoming, it would not be better to make a more permanent work.

Mr. W. A. Brooks said rather more than a quarter of a century ago he was called upon by the Admiralty to hold many Courts

of inquiry upon the rivers in the Fen districts, as they were affected by the works then about to be brought before Parliament. He was greatly indebted to many of the engineers in the district for the production of valuable plans and sections, especially of the rivers Witham, Nene, and Ouse, which were now in the possession of the Admiralty. When he had finished his inquiries in 1848 he was struck with the want of regularity in the works—the want of some mode of bringing the rivers into one common channel; and he drew up a rough plan having that object in view, which he now exhibited. It appeared to him that the engineers who had been recently employed had not paid sufficient attention to the tidal volume, or element for procuring deep and capacious channels. The channels were nearly all of the same breadth for many miles, as if they had no tidal water to receive, instead of being gradually enlarged as they approached the sea. The consequence was that the tidal water was choked; and whereas formerly the tide rose at Peterborough to within 5 feet of the level of the river at Sutton Bridge, there was now, without going so far up the river, a depression of 13 feet 6 inches. The same thing might be said of the Boston river. The result of the contraction of the river, instead of the expansion, in the lower reaches, was seen in the map exhibited by the Author. It would be observed that at the termination of the sea works in the Nene there were several sharp curves or curvilineal reaches, and wherever the current crossed from one side of the channel to the other the result was a diminution of the depth in the navigable channel, forming in such crossing a bar or natural weir, proving that the water had not a free discharge. No doubt the work of combining the entire power of the rivers would be a costly one, but it should be carried on gradually. The mischief had been working without a general plan for more than a century and a half.

Mr. Benedict had listened to the Paper in the hope of getting some hints as to how to train alluvial rivers. He was particularly interested, because the circumstances seemed similar to those he had had to deal with in the Ganges, where fascines could be easily made, where stone could not be obtained, and where broken brick might represent the chalk used in the Fen rivers; but there were, he thought, reasons why such works could not be carried out in India. Two circumstances were necessary to their success. First, the silt overlying the clay should be of such a nature that the fascine work, when weighted, would settle evenly, otherwise he did not see how a jetty formed of fascines and clay could be designed with such slopes as $\frac{1}{4}$ to 1; for if there was any scour on

the inside of the channel the bank would be tilted so as to bring it perpendicular in a short time, and the work would then be in an awkward state. Secondly, the clay should be of such a tenacious character as to resist the increased scour when the channel was contracted. It appeared that for many miles the clay described was of that character, and that there was no fault in it. He knew of no place in India where those conditions existed. In the alluvial rivers he had referred to the clay was in patches, sometimes thick and at other times thin, and in no case could it be depended upon. Moreover, the silt overlying the clay was of such a character as to scour on one side more than on another, and not become a quicksand, except in unusual cases; so that a bank formed in the way described would tilt up, and perhaps in time turn over. At any rate, if the silt scoured unevenly much flatter slopes to the banks would be required, and that would increase the cost.

Sir John Coode could fully indorse the remarks of the Author with regard to the beneficial results which had followed the training of the Ouse, the Nene, and the Witham, by fascine banks. That the outfalls had been lowered and the navigation improved was notorious to all who were acquainted with the district, which was, in those respects, as the President had stated, one of the most interesting in the country. He might mention that, in consequence of the removal of the Old Sutton Bridge, on the recommendation of the late Mr. Robert Stephenson, Past-President, Inst. C.E., the river had been lowered there to the extent of 2 or 3 feet, and a great improvement had consequently been effected, altogether independently of that produced by the construction of the training banks at the outfall of the Nene. There was, he thought, a little error in the chart exhibited, the training walls being straighter than they were represented. The Author had laid down the rule that every stage of reclamation might be represented by a term of thirty-five or forty years. In that, as in most other cases, however, it was impossible to draw a hard and fast line. He believed from twenty to fifty years would perhaps embrace the ordinary limits of such reclamation periods. In a case in which he was concerned, on the Humber, the last three reclamations had been at periods of about twenty-five years, namely, in 1802, 1826, and 1851, and in the course of the next summer there would probably be another reclamation of 800 acres. He agreed with the Author in regarding the process of faggoting as the best means of expediting the accretion of the warp; but there was one point he wished to mention, of great importance, and that was the cutting of what were locally termed grips, or

channels to let off the tidal water; these produced a striking effect, which could only be realised by those who had seen them. In the majority of cases, in the soft warps, there was a tendency to form pits or 'pans,' and if they were allowed to remain, no steps being taken to warp them up, the agitation of the wind created a wave, and they were gradually enlarged so as to interfere materially not only with the period of reclamation, but with regularity of the surface, and consequently with the value of the land when reclaimed. The formation of grips at about 2 chains apart, so as to draw off the tidal water, had a most beneficial effect in bringing up the new land in a remarkably level form, and rendering it more fitted for inclosure than by any other process. It was a cheap method, and he could recommend it for reclamation works. The cost of inclosing was set down by the Author at £15 or £20 an acre, but that would depend upon a variety of circumstances, such as the amount of matter in suspension in the water, the sheltered area, and the like. He would himself prefer to adopt the limits of £10 or £30 an acre as the cost of reclamation. The broad results of the works constructed in the estuary of the Wash were, he thought, remarkable examples of the beneficial effect of the adoption of longitudinal training walls as against the exploded system of cross jetties.

Mr. Shoolbred said a very successful application of the system of fascine training walls was to be seen on the river Gironde between Bordeaux and the sea. Parts of the river were wide, and the channel at one time was tortuous. Almost the whole of the channel had been successfully confined within narrow limits by fascines, and the land on each side had been extensively reclaimed. In the river Ribble, also, training walls had been successfully adopted, though he was not sure whether fascines were used. He concurred in the remark, that if the channels of the upper estuary of the Mersey were to be guided and controlled, it must be by fascine half-tide training walls, which alone would be likely to have any permanency, in consequence of their lightness, in the case of such extremely mobile sands.

Mr. Redman called attention to a diagram with a view of illustrating the conditions of the estuaries of the Mersey and the Wash. It was prepared for him by Mr. Turner, assistant curator of the Royal Geographical Society, and its accuracy might be depended upon. It showed, by bands of colour, the course of the flood streams surrounding the British Islands. The band was to a scale representing the vertical oscillation, so that the general height of the tide along the coast could be ascertained from the

breadth of the band. The times and the vertical oscillation were also shown in Roman and Italic numerals as compiled from the yearly time-tables of the Hydrographical Department of the Admiralty. The general ocean depth was also shown, and the neutral points or nodes of tide to which he had referred in the previous discussion.[1] The double stars denoted local meetings of the tidal streams as in Morecambe Bay and elsewhere. There were likewise diagrams of the three pulsations of the tide making the entire circuit, showing how the high and low water at the extremities of those tidal pulsations (the flood and ebb being reversed) intersected each other. He had explained on the former occasion the reason for the exceptional condition of the tide in the estuary of the Mersey; and the diagram plainly showed that the tidal conditions of the Wash were equally exceptional, because not only had the Wash a great oscillation of tide (23 feet ordinary springs and 26 feet equinoctial springs), but it was also remarkable for the great rapidity of its current, amounting to from 4½ to 5 knots an hour. The range of ordinary spring tides was at

	Feet.	Inches.
Boston Deep, Clay Hole	23	3
Lynn Deep, Long Sand	23	0
Lynn Road	23	3
Lynn	22	6

Ten years back the last was only 18 feet, so that the new straight cut below Lynn had produced an increased oscillation of tide of 4 feet 6 inches. This afforded evidence of the large field open for the improvement of the outfalls of the Wash rivers by fascine works, and how the tide was checked at these outfalls when unimproved, the rise of the tide thereat being no gauge of that of the Wash proper. It would be seen from the diagram that the projection of the Norfolk coast caused a heaping-up of water, which accounted for the oscillation of tide; and the enormous amount of detritus was accounted for by the rapid wearing away of the coast to the northward. The same kind of operation was going on in the estuaries of the Humber, &c.

Sir John Coode believed Mr. Redman was wrong in his statement with regard to the rise of the tide in the Wash. He believed only about fifty tides in the year attained a greater elevation than 20 feet, and there were not more than sixteen tides in the year which reached a greater height than 21 feet. That was the result

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[1] *Vide ante*, p. 58.

of some abstracts which had been made within the last few weeks to determine that point.

Mr. Redman said that 23 feet was the height given in the Admiralty time-tables.

Mr. Wheeler, in reply, said the object of the Paper was to show how, at a small cost, rivers might be trained through sandy estuaries. For £1 per foot many estuaries might be trained in which the cost of stonework would entirely preclude improvement. There were many small rivers, used simply for drainage, in which it would be impossible to employ stone, but which might be improved by fascine work in the manner described. With regard to the use of 'clunch,' as suggested by Mr. Shelford, the smallest price at which that could be obtained was 8*s.* or 9*s.* per cubic yard, whilst the cost of fascine work was only 1*s.* 8*d.* a cubic yard. With reference to a stone bank, if it was a solid structure the waves striking it carried their force throughout the whole length, while fascine work was buoyant and elastic, and the wave simply gave it a shock and passed harmlessly over it. Fascine work, therefore, was adapted to a sandy estuary where stone would be washed away. As to the alleged necessity of an even bottom, it was one of the advantages of fascine work that that was quite unnecessary. In his own case, the bottom was most irregular in places; and, from the nature of fascine work, it hung together like a mattress, gradually settling itself till it found its own bottom. In the Welland, where clay could not be found with the same facility, sods off the marsh had been used for weighting the fascines, and had answered remarkably well. Any kind of clay that would weight the fascines and carry them down would be sufficient to hold them together. With reference to the remarks of Mr. Brooks, as to the contraction of rivers in the Fens, and the damage done by confining the channels too much, the complaint as to the Witham was that it was too wide, and that shoals gathered in consequence. It had been stated that harm was done in withdrawing a large quantity of tidal water, and that the wider the rivers were the better. He believed from his own experience that it did not matter what quantity of water came down a river; unless it was confined within reasonable limits no advantage was obtained from it. When it left the trained portion of the channel it spread itself out and was influenced by wind and tide, its whole force being expended in turning over the sands in various directions. If the channels were confined by training walls, the force of the water was exerted in keeping a deep channel, and consequently lowering the low-water

mark. Such a work as had been suggested would be a gigantic undertaking, and beyond the means of any public body; neither was it necessary, because the low water in the river Ouse was now nearly brought up to Lynn, and if the training works were carried out for another mile or less, low water in the estuary would be brought up to that point. He admitted the error pointed out on the chart by Sir John Coode; no doubt the walls should have been a little straighter.

May 9, 1876.

WILLIAM HENRY BARLOW, Vice-President, in the Chair.

No. 1,476.—"On the Construction of Railway Wagons, with special reference to Economy in Dead Weight." By WALTER RALEIGH BROWNE, M.A., Assoc. Inst. C.E.[1]

THE present Paper is mainly an essay towards determining the best and lightest form of goods wagon for general purposes to run on an ordinary English railway. It is, of course, a chief condition in such a wagon, that it shall enter readily into combination with the stock at present in use. The Author has therefore left unnoticed many points which it would be proper to discuss were the question that of designing the best type of vehicle for a new and independent system of railways. As an example, may be mentioned the various systems of central buffer and draw couplings which have lately come into extensive use on new foreign lines, especially those of a narrow gauge. Whether these, in their own place, are beneficial or not, there can be no question that any vehicle intended for English main lines must have side buffers, placed at the same height from the rails, and the same distance apart, as those with which it will everywhere come in contact. For a like reason, while attention has been given to the practice of the best railways on the Continent and in America, this has only been considered as illustrating and throwing light upon the various characteristics of the English system. It was originally intended to include the subject of carriages as well as wagons; but this proved at once so large and so distinct, that, with the limits of time and space allowed, it was impossible to discuss it properly. Although alike in their principal parts, a carriage and a wagon differ widely in their essential conditions: not merely must a carriage be adapted to a much higher speed than a wagon, but considerations of smoothness, comfort, and luxury, wholly wanting in the latter, are of paramount importance in the former. Hence, although considerable information had been collected on the subject of carriages, it was thought better to reserve this for some future occasion.

The designing of a railway wagon has its peculiar difficulties,

[1] The discussion upon this Paper was taken in conjunction with the succeeding one, and occupied portions of three evenings.

arising from the fact that, in addition to the ordinary strains, which can be calculated and allowed for, such a wagon is also subject to sudden and extraordinary strains which defy calculation. The violent shocks and strains of all kinds which a wagon is continually called on to endure need no description to any one who has ever watched the handling of goods traffic on railways. It is these which have chiefly to be considered in the building of a wagon. Extreme cases, such as a collision, or what Americans call a "derailment," cannot, of course, be guarded against; but the leading principle must be that all parts should be strong enough to sustain, without injury, the greatest shocks to which they are liable in ordinary working. It has not, therefore, been attempted to give a complete theoretical investigation of the strains on a wagon, or to frame a design and dimensions on theoretical principles. The dimensions found in the practice of the leading English railways have in general been assumed as substantially correct. What has been aimed at is to compare these with each other (checking them also by theory wherever possible), and thus endeavour to arrive at the lightest and most economical design consistent with the practical conditions of the case. These lead at once to the principle just stated, viz., that the strength of a railway vehicle must not, as in other structures, be proportioned to the load it has to carry. To show this by an example, take the ordinary sole-bar of an 8-ton or a 10-ton wagon. This, following the dimensions specified by most railway companies, will be a piece of American oak, 12 inches deep by 5 inches wide, and carrying a distributed load over a length of about 14 feet. Taking 10 tons as the load, and 4 tons as the weight of the wagon itself (exclusive of wheels, axles, and springs), this distributed load will be 7 tons, or just $\frac{1}{2}$ ton per foot. This load is supported on the two axles, which may be taken at 8 feet apart. On calculating the bending moments at the centre of this wheel base and over the axle respectively, it will be found that the latter is the greatest, and that its value in inch-tons is $\frac{3}{2} \times 18$, or 27. But calculating the breaking strain of a 12-inch by 5-inch section in the ordinary way, and assuming 4·7 as the modulus for inch-tons, the moment of rupture is found to be 564. This gives a factor of safety of 21, or at least double what would be required in an ordinary timber structure. It follows that some other consideration must have led to the fixing of this scantling; and this of course lies in the fact, that the sole-bar has not merely to carry the load, but to carry it under all the varying circumstances of shock and strain which have already been alluded to.

It might seem an obvious deduction from the foregoing that the load of wagons (meaning thereby the total weight carried, in opposition to the 'tare,' or dead weight) ought to be largely increased. If the underframe of a wagon must in any case be made so strong that it would carry 20 tons as easily as 10 tons, would it not be true policy to put something approaching to 20 tons upon it? This leads at once to the question, which ought obviously to form the first stage of inquiry, viz.: What is the proper load for an ordinary wagon?

Since, as already stated, the dimensions, and therefore the weight, of a wagon framework are, for the most part, fixed by considerations other than the weight it has to carry, the leading principle in this inquiry would seem to be that the load should be as great as possible. The way in which this principle has worked is shown by a glance at the history of railway rolling stock. The wagons first built carried only 3 or 4 tons, and weighed as much or more. From this the load was gradually increased to 6 tons, and then to 8 tons and 10 tons, at which it has stopped, although still the wagon is too strong for its load. Between these last two sizes the question may be said practically to lie. It is true there are still many 6-ton wagons running, but few are now built, at any rate by railway companies themselves; in fact, the weight and cost of a 6-ton is not much below that of a 10-ton wagon, while the load is little more than one-half. The question being thus narrowed, the difference between the weight and cost of an 8-ton and a 10-ton wagon has to be considered. It must be admitted that this is not great. Plate 9, Figs. 1 and 1A show an ordinary 8-ton coal wagon, as built by the Bridgwater Engineering Company, to run on the lines of the Great Western Railway Company (the Author's firm), and to pass their inspection. Fig. 2 gives a plan of the underframe. This underframe is entirely of oak, the sole-bars, headstocks, and middle bearers being all 12 inches by 5 inches, and the diagonals 11 inches by 3 inches. The wheels (Fig. 3) are 3 feet in diameter, with eight pairs of wrought-iron spokes, and weldless iron or Bessemer steel tires, 5 inches by 2 inches, secured to the skeleton by rivets. The axles are 5 inches diameter within the boss, and 4¼ inches diameter at the centre, the journals are 7 inches by 3½ inches. The bearing springs are 3 feet 3 inches long by 3 inches wide, and consist of twelve plates each ⅜ inch thick, and one plate ½ inch thick. A similar wagon to carry 10 tons differs from the above only in a few particulars. It is longer and deeper, the length being 13 feet 7 inches, and the depth 3 feet 6 inches.

The underframe is the same, except as to the longitudinals. In the 8-ton these only run between the middle bearers, and are 11 inches by 3 inches: in the 10-ton they are 1 inch wider. In the end spaces the 8-ton has only two light pieces, 4 inches by 3½ inches, above and below the drawbar; whereas the 10-ton has an 11 inch by 3 inch longitudinal running on either side the drawbar. It has also 1⅛-inch longitudinal tie-rods in place of ¾-inch tie-rods in the 8-ton. The wheels are the same, but the axles are 5¼ inches inside the boss and 4½ inches at the centre, the journals being 8 inches by 3¾ inches. The bearing springs are of the same length and design, but are 4 inches wide instead of 3 inches. The ironwork is the same throughout. The weight and cost of these extras are not great; in fact, while the tare of the 8-ton wagon is about 4 tons 7 cwt. that of the 10-ton will not be above 4 tons 14 cwt.; and, taking the price of the former at £60, that of the latter will not rule above £64. This comparison would appear to prove that the 10-ton wagon was decidedly the proper type, and that, as even here the factor of safety is far too high, a yet greater load might be resorted to. This conclusion, however, is negatived by the two following considerations:—

(A) Wagons have not only to be hauled by locomotives; they have also to be shifted by horse power in yards and sidings: obviously, therefore, it is a fatal objection if a wagon is too heavy for a single horse to move it. Now it requires all the strength of a powerful horse to start a 10-ton wagon, fully loaded and in ordinary working order, upon a dead level: to start it on anything like an incline is too much for him: hence 10 tons is, at any rate, the extreme limit admissible for the load.

(B) It is comparatively seldom that a wagon is loaded up to its full capacity. This arises from several causes. Thus (1) The contents of a wagon are often too bulky to make up the full weight. (2) The whole quantity of goods to be sent is often less than this weight: a truck comes into some private yard and is loaded, say, with 3 tons of castings, which are quite sufficient to constitute what is called a 'truck-load': it is returned to the station, and thence goes direct to its destination, no weight being added, because nothing else offered having the same consignment. (3) The goods traffic on a railway is seldom equal in the two directions: hence wagons have constantly to be sent back empty. There are, unfortunately, no statistics with respect to English railways which will enable a judgment to be formed of the effect of these causes, and so to approximate to the average load of a wagon. For the railways of France, however, such statistics do exist,

though not in a perfect form. These have been ably analysed and discussed by M. Ernest Marché.[1] Taking the six great railway systems of France, he finds that the ratio of the mean load to the capacity (or greatest load) of a wagon varies from 0·37 on the Chemin de Fer de l'Est to 0·444 on the Chemin de Fer du Nord: the average being exactly 0·4. On three of these railways the effect of the return of empty wagons can be separately estimated, as the number of these empties is registered: the percentage of these in the three cases was 25·35, 20·46, and 14·89 respectively. Eliminating this effect, the mean load of the wagons actually freighted can be ascertained: in these three railways its proportion to the capacity was 0·495, 0·472, and 0·473 respectively. The sum of his results amounts roughly to this: that on the railways of France one wagon in five is running empty and the other four are loaded to rather less than half their carrying capacity. For English lines, as already stated, no such data are available. It is possible that, from their much larger mineral traffic, they would show more favourable results: but the difference probably would not be great. Looking at these figures, and remembering that the extra weight and cost of a 10-ton wagon are entirely wasted whenever its load does not exceed 8 tons, it would seem that the latter is probably the best figure to take for purposes of general traffic. An exception may arise in the case of coal or ore wagons owned by private firms and used only for a single purpose. These are commonly loaded at the pits to their full weight, and in such cases the shunting is so generally done by engine instead of by horse power that the other evil is not so important. Taking, however, an ordinary goods wagon, such as railway companies use for general purposes, the case may be summed up by saying that even if built for 10 tons it will rarely have more than 8 tons to carry, and that when it has, its cumbrous weight will be likely to cause trouble both at the beginning and at the end of its journey.

For these reasons in what follows 8 tons will be taken as the standard capacity; and an investigation will be made of the best design for an 8-ton wagon, in all its parts. The conclusions arrived at will apply, with little variation, to a 10-ton wagon.

Before entering on this, however, there is one other point which it is necessary to discuss. This is the question, whether it is wise to provide as far as possible special types of wagon for the various

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[1] "Le Poids mort dans les Transports sur Chemins de fer, &c." E. Lacroix, Paris, 1871.

classes of traffic. This proposal has often been made, and is certainly plausible at first sight. As it has been put to the Author, a heavy wagon may receive, say at High Wycombe, a consignment of cane-bottomed chairs, to be delivered at Bristol; and though built for 10 tons, will be thus travelling with a load amounting only to a few hundredweights. Or again, the Great Western railway forwards daily throughout the spring many trucks full of cauliflowers, grown in Cornwall, but destined for the London market. In these and all similar cases there is no doubt that special types of light wagons might be designed which would offer great advantages for the conveyance of these particular loads. But this course is open to two fatal objections.

(1) Suppose the light wagon to have deposited its freight of chairs at Bristol. It has then to be sent back, and it is of course desirable that it should not go empty. But the goods going from Bristol towards London are not of a light character, and perhaps the only consignment offering is a ponderous casting, or some heavy barrels of sugar. There is then only the choice between sending the wagon back light, or loading it beyond its proper capacity.

(2) Whether loaded or not, the light wagon will have to travel as one of a long train of wagons, most or perhaps all of which are of a much heavier and stronger build than itself. In cases of accident, or in the ordinary events of shunting, starting, and stopping, the light wagon will be much in the position of the earthenware pot in the fable; it will meet with so much rough usage, will be so mauled and hammered by its neighbours, that its life, under the most favourable circumstances, will be of short duration.

These two considerations seem fully to justify the course which has been taken by railway companies, both here and on the Continent, in reducing as far as possible the number of classes of wagons. There must always, however, remain a considerable number of varieties to provide for traffic to which ordinary wagons are unsuitable. The chief of these, as at present existing, are cattle wagons, timber wagons, coke wagons, platform wagons for heavy masses, such as boilers; covered wagons for perishable goods, &c. But much may be done to economise even these: thus cattle wagons may be used for coke, or at another time for light bulky articles, such as would generally be carried in covered wagons; boilers may be conveyed on timber wagons, and so forth. Far from agreeing with those who would wish to see classes of wagons multiplied, the Author's view is exactly the opposite. The end which

should, in his opinion, be aimed at is to have all ordinary wagons, not only on one railway, but throughout the kingdom, of precisely the same type and dimensions; this type being that which study and experience finally decide upon as the best. To help towards such a decision is, in fact, the principal object of the present Paper. Many advantages would result from this uniformity in wagons, which would of course extend to all their parts. A wagon, no matter what district it was built for, would always be free to work in any part of the country; whereas now it continually happens that a wagon is admitted without question by one railway company, which would be refused registration by another, as not complying with some special regulation. The wagons of the Taff Vale railway, for instance, are essentially different from those of all other companies, and would not be accepted by them: while a wagon that would be free over the whole vast system of the Great Western would not be admitted on the Taff Vale. Again, any proposed improvement in design would of course have to go before a committee of wagon superintendents, and would thus at once be more easily brought to notice, and more thoroughly tested before approval. But the chief advantage would lie in the facility of repairs. All working parts being uniform, there would be no difficulty in keeping a stock at every repairing station, which would thus suit every wagon that could possibly arrive; and the cost of effecting every sort of repair would be accurately known, and could be charged according to a fixed schedule. On this system railway companies might with great advantage undertake the whole repairs of wagons in their district, and thus do away with the present system of repairing contracts, with which they profess themselves dissatisfied. The matter would be as simple as possible. On a wagon being stopped at a station the foreman in charge would notify to the owner the repair required, and proceed to execute it. There could be no question as to the charge, and the amount of this might be collected, if advisable, before the wagon was allowed to proceed on its journey. This would do away with all the objections now felt to freighters' wagons, as it would insure that they were kept up to the same standard of efficiency as those belonging to the railway companies themselves. This would be an advantage also to the freighters themselves, and they would also reap the benefit of getting all breakages repaired without an instant's delay; whereas a wagon is now frequently kept idle for days or weeks, while an axle-box or buffer-case of a special pattern is obtained from the only place, perhaps hundreds of miles distant, at which it can be manufactured.

Having, then, decided that the load of the standard wagon is to be 8 tons, and that it is to be of a form as generally useful as possible, the next consideration is its design in detail.

For this purpose a wagon may be divided into the following parts, beginning from below:—

A. Wheels and axles.
B. Axle-boxes.
C. Springs.
D. Underframe, axle-guards, &c.
E. Draw-gear.
F. Buffers.
G. Body.

A. *Wheels and Axles.*—Diagram 3 represents the type of wheels and axles commonly employed for ordinary freighters' wagons in this country. It consists of a cast-iron nave or boss, wrought-iron spokes cast into it, and bent round to form a skeleton on which a steel or weldless-iron tire is shrunk and secured by rivets.

The diameter of the axle is 5 inches in the wheel seat, and $5\frac{1}{8}$ inches just inside the wheel, thus forming a shoulder; thence it tapers to $4\frac{1}{4}$ inches in the centre; while outside the wheel it is reduced to $3\frac{1}{2}$ inches for the journal, which is 7 inches long. These dimensions do not vary much from those in use on the chief systems both at home and abroad. Thus the Great Northern Railway Company specify 5 inches in the wheel seat, but reduce to 4 inches in the centre, and $3\frac{1}{4}$ inches in the journal. The London and North-Western railway agree with these, but are content with $4\frac{3}{4}$ inches in the wheel seat. The Paris and Mediterranean give 5 inches in the wheel seat, $5\frac{3}{16}$ inches at the shoulder, $4\frac{1}{8}$ inches at the centre, and $3\frac{3}{8}$ inches in the journal. The Cambrian railway and the chief German railways, however, are content with $4\frac{1}{2}$ inches for the diameter in the wheel seat; and the Grand Trunk of Canada specify $4\frac{1}{4}$ inches only, tapering to 4 inches in the middle.

The great diminution in size, both at the journal and in the centre, is, at first sight, hard to account for. The axle may of course be considered as a beam, loaded at each end (in the journals) by the half weight of the truck, and kept in equilibrium by the two upward pressures of the rails, passing through the wheels. It thus is under the action of two equal and opposite couples, in which the force is half the weight of the truck, and the arm is the distance between the centre of the journal and the centre of the boss. As the effect of such a couple is precisely the same at every point

of the axle, it would seem that the diameter should also be the same everywhere. But it must be obvious that an axle is never endangered by the regular statical load brought upon it: its fracture is always occasioned by some sudden shock, such as might be caused by a stone placed on one of the rails, when the whole axle will act, for the moment, as a beam fixed at one end and receiving a blow at the other. This will of course produce its greatest effect at the fixed end, *i.e.*, in this case close to the undisturbed wheel; from thence the effect will diminish to its lowest value at the other, or disturbed wheel. This is the reason of the reduced diameter at the centre, the strain there being always less than at one or other of the wheels. The diminution is of course proportional to the moment of resistance, and therefore to the moment of inertia of the section: as this in a circle varies as the fourth power of the radius, the ratio of the diameter at the centre to that at wheel seat should equal $\sqrt[4]{\frac{1}{2}}$, or 0·84, a proportion very near to that found in practice.

The utility of this diminution has been questioned by M. Couche;[1] but the above reasoning seems fully to demonstrate its theoretical soundness, while practically it effects a considerable saving in weight and cost.

The same reasoning, of course, accounts for the well-known fact that axles generally break just inside the wheel seat. This point is, in fact, that at which the cantilever is fixed (considering the axle as such), and therefore at which the intensity of strain is greatest. It is therefore desirable to avoid anything which may tend to weaken the section at this point. On some railways it is the practice to have a shoulder about $\frac{1}{8}$ inch deep on the axle, just inside the wheel, to prevent the latter from working inwards. The great tightness, with which wheels are now fastened to their axles, seems to render this unnecessary, and, in fact, on many lines it is dispensed with altogether. In any case, the difference between the first and the finishing cut of the lathe used in turning down the axle would seem to be amply sufficient. Anything more than this is objectionable, from the well-known fact that an abrupt change of section, in any piece subjected to impulsive strains, has a marked tendency to produce fracture. This, which has long been recognised and acted on in the case of shoulders, is probably also the reason why keys have frequently been condemned as means for fastening on wheels. But this would seem erroneous; for, in the case of a keyway, the shoulder runs parallel, and not at right angles

[1] "Voies, Matériel, &c., des Chemins de fer," vol. ii., p. 109.

to the direction of strain, and can therefore have no actual tendency to produce fracture. A keyway must of course be to some extent a source of weakness by diminishing the diameter; and to this is probably due the fact, observed[1] by French engineers, that the fracture of an axle usually begins at the point diametrically opposite to the keyway. It is now becoming the practice to dispense with keys altogether, and simply to use so powerful a pressure in forcing the wheel on to its axle, that the adhesion so produced is sufficient to keep the wheel tight under all possible strains. It may, however, be questioned whether this is not itself dangerous in another way. The wheel being thus, as it were, incorporated with the axle, the latter is somewhat in the position of a piece whose section alters suddenly and to a large extent. The evil of this is well known, and has been already alluded to. At the same time the boss is put into a state of violent strain (at least in its inner portion), and it is thus liable to split when any shock comes upon it. The splitting of bosses is, in fact, of frequent occurrence.

Looking at these considerations, there seems great want of a method for uniting these wheels and axles which should be sufficiently firm, without throwing either into a state of internal strain. An obvious method would be to make the wheel seat oval or hexagonal, instead of round; but this would, no doubt, add to the expense of machining. Perhaps the single key as now used, with some simple arrangement to prevent the possibility of its working loose, is as good a system as exists at present; at any rate, until some better be devised, 4½ inches at the wheel seat, tapering to 4 inches in the middle, would seem to be the smallest diameter permissible for an axle.

The greatly diminished size which may be given to the journal is due to the fact previously noticed, viz., that it is a blow delivered by one rail which produces the most violent strain on an axle. Another cause, however, no doubt comes in to assist the journal, and that is the operation of the bearing spring, through which the weight is transmitted. When a wheel passes over an inequality, the weight of the truck must of course come heavily down upon the journal; but the effect is taken off by the yielding of the bearing spring, and changed from a violent blow into a gradual pressure. This leads to the inquiry whether the shock to the wheel seat might not be, to some extent, 'cushioned' in a similar manner. This clearly implies the giving of a certain amount of elasticity to the wheel itself; and this has apparently been accom-

[1] Couche, vol. ii., p. 116.

plished in the wooden wheel system, now so frequently used, especially for carriages. The space between the boss and the tire is here filled up by a series of hard wood blocks, set endwise to the fibres, and secured both at the boss and the tire by rings of plate iron. This system has been in use on the London and South-Western railway for thirty years. The wood used in the first wheels was teak, which was saturated with oil and whitelead by a process similar to creosoting, *i.e.*, by placing the blocks in a receiver, first exhausting the air to remove the sap, and then forcing in the oil and lead under a pressure of 90 lbs. to the square inch. Some of these wheels have lately been taken off and cut down to a smaller diameter; and the Author is assured by Mr. W. G. Beattie that the wood was perfectly sound. He was at the same time informed that the breaking of an axle had never been known to take place with these wooden wheels—a result which can only be due to the elasticity they possess. These wheels are lighter than ordinary iron wheels, the total difference being as much as 3 cwt. per pair; and their first cost is not much greater. The tires rest directly on the wood, so that no skeleton is required, and are of course secured by some kind of clip fastening, and not by rivets. This is not the time to discuss the vexed question of riveted tires; but it cannot, of course, be denied that a rivet-hole must make a weak place in any piece, especially one so heavily strained as a tire; and now that other fastenings can be provided at little extra cost, it may be doubted whether the time has not come for giving up the old system altogether.

In the sharpest possible contrast to the elastic wooden wheel is the chilled cast-iron wheel so much in vogue in America. The merits of this have been more than once discussed in this place, and also the question of its manufacture in England. It is believed that there would be no real difficulty as to the manufacture, provided pig iron of the requisite purity were used. This would now have to be obtained from Sweden, Russia, or elsewhere; but should a demand spring up, charcoal blast-furnaces (of which one still exists at Lorne in Argyleshire) would probably soon spring into being. The excessive rigidity of this wheel would certainly seem to form an objection to it; though this would appear not to have been felt in the States, where the permanent way is often of the roughest description. Possibly the curve which is usually given to the section between the boss and tire, in order to allow for contraction, may give to the wheel, when in use, a certain degree of elasticity.

Before leaving the subject of wheels and axles, it should be

noted that one important point to be aimed at is the prevention of the wear of the journals. The skeleton and boss of a wheel, and the whole length of the axle, are practically subject to no wear and tear whatever; and though tires wear out, they can easily be renewed. Thus the life of a pair of wheels would be indefinite were it not that the journals wear down, and the wheels are then useless. An obvious remedy is to 'bush' them with brass or white metal; but as obvious an objection is, that the arm at which the bearing friction acts would thereby be increased. Another device would be to make the journals in separate pieces and screw them into the ends of the axles; but there might then be fear of their working loose. This point is one which would seem worthy of attention.

B. *Axle-boxes and Axle-guards.*—The next part of the wagon to be considered is the axle-boxes, involving the important question, whether oil or grease should be preferred as a lubricant. At present oil is universal in hot climates, is general in Germany and in the United States, and is largely used in England by railway companies; but grease is, in this country, almost the only lubricant used for private wagons. The advantages of the latter are its cheapness and facility of application. The real ground of its use is probably the much greater cost of an oil axle-box: thus Beattie's and Beuther's axle-boxes each cost about £5 per set, exclusive of royalty; while ordinary grease axle-boxes weigh less than 3 cwt. per set, and cost little over £3. The advantages claimed for the oil axle-box would seem to outweigh this difference in prime cost. These are: (*a*) The quantity of the lubricant used is so much smaller that it needs to be renewed very seldom. (*b*) Should the supply run short, the box heats, not suddenly, like a grease box, but gradually, taking two or three days to arrive at a dangerous temperature: this of course enormously increases the chance of its being discovered in time. (*c*) There seems no doubt that the friction resistance is decidedly smaller with oil than with grease, a point of vital importance. A comparison made some years back, between the vehicles of the Orleans railway, using oil, and those of the Lyons railway, using grease, did not prove any marked difference between the two;[1] but in a comparison of this kind the result may be affected by so many other conditions that it must always be regarded with suspicion. On the other hand, the experiments of M. Vuillemin and others showed a great superiority on the side of oil; and these have been confirmed by

[1] Couche, vol. ii., p. 96.

experiments on the London and South-Western railway. The general result of these was that with oil the resistance to traction of a wagon in motion was only 3 lbs. per ton, while with grease it was about 9 lbs. On the other hand, the resistance of a wagon at rest to being started was somewhat greater with oil than grease, but the difference was not large (15 lbs. and 13 lbs. per ton respectively). Should railway companies, as previously suggested, take in hand the repairs of all wagons running on their system, they would probably provide for the greasing as well, charging a moderate sum per annum, which owners (to whom greasing and hot boxes are a perpetual source of trouble) would in general be most willing to pay. It would then probably be much to their advantage to forbid the further manufacture of grease axle-boxes altogether, and settle upon some definite system of oil lubrication.

With regard to axle-guards, the W-shape, now universal, probably admits of no improvement. The thickness of the iron, $\frac{3}{4}$ inch, is also fixed by general consent. Its width, however, is generally, in the Author's opinion, excessive: on many railways $3\frac{1}{2}$ inches is still the minimum. It is believed that (where the iron is, as it ought to be, first-rate) a width of $2\frac{1}{2}$ inches is ample, even for the crowns, and that for the wings $2\frac{1}{4}$ inches is sufficient. It must be remembered that both the pulling and the buffing strains are transmitted through the body of the wagon; consequently the stress thrown on the guards by sudden stopping or starting is only that due to the momentum of the wheels and axle, weighing together about 14 cwt. This can never be very great; and, even with the moderate widths now used by some railways, the fracture of an axle-guard is almost unknown.

C. *Springs.*—It is remarkable that conical bearing springs are general in America, but are unknown in this country. A comparison between these and the common laminated springs would be interesting, but it has not been possible to obtain the requisite data for making it. The spring of the Highland railway is flat and long, like a carriage spring, consisting of nine plates $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch; the uppermost 3 feet 6 inches in length. On other lines the plates have a decided camber; their width varies from 4 inches on the Caledonian to 3 inches on the Great Western, and whilst in the former case they are ten in number, each $\frac{1}{2}$ inch thick, in the latter there are two plates $\frac{3}{8}$ inch, and fourteen plates $\frac{5}{16}$ inch. A much lighter spring is that used on the Cambrian railway, which consists of ten plates 3 inches by $\frac{3}{8}$ inch, and one plate 3 inches by $\frac{1}{2}$ inch. Probably a simpler form even than this would suffice. In

a wagon great flexibility is not necessary; and strength is best consulted by making the plates few and thick; since in a laminated body the several parts act almost independently, and the sum of their strengths gives the real strength of the whole. Hence, as the strength of a beam varies as the square of its depth, six plates $\frac{1}{2}$ inch thick will more than equal ten plates $\frac{3}{8}$ inch thick; and it would seem that a spring consisting of only seven plates 3 inches by $\frac{1}{2}$ inch would have sufficient strength, and probably also sufficient elasticity. Such springs would not weigh above 2 cwt. 2 qrs. per set, in comparison with 4 cwt. 2 qrs. 20 lbs., the weight of Great Western springs.

D. *Underframe.*—Plate 9, Fig. 2, shows the plan of an ordinary oak underframe for an 8-ton wagon. It may be worth remarking that the diagonals should always incline from the centre towards the buffers, and not, as sometimes seen, from the ends of the middle bearers towards the drawbar. In the latter case they give no assistance against the pull of the draw-gear, because they cannot act as ties; in the former they are able to assume their proper function as struts, and thus help to support the 'buffing' strains.

This difficulty as to ties constitutes, in fact, the chief disadvantage in wooden structures. In an underframe it compels the use of wrought-iron tie-rods both along and across the frame. Looking at this, an underframe of combined wood and iron would seem desirable, in which angle or T-irons should act both as supports and ties; but such combinations are rarely successful. Carrying the same idea still further, many engineers have built underframes wholly of iron, but the advantage of this is more than doubtful. For on comparing the properties of American oak and wrought iron, as given in Rankine's Rules and Tables, p. 195, it will be found that the following is approximately true: a bar of iron in comparison with an exactly similar bar of oak has five times the strength to resist tearing, six times the strength to resist crushing, and four times the strength to resist cross-breaking; but, on the other hand, it has ten times the weight, and twelve times the value. Hence to have, say, a sole-bar in iron of the same strength as one in oak, one-sixth the scantling must be given; but in that case it would weigh 66 per cent., and cost 100 per cent. more than its rival. This result is completely borne out in practice. The weight of the oak underframe shown in the diagram is about 12 cwt. (including tie-rods, &c.); and its cost at present rates is about £7 12*s*. But an iron underframe of the same general character and size, if made with the usual dimensions, would weigh about 16 cwt., and cost about £15 13*s*. Against so large a difference, there seems only one

point to urge in favour of iron, and that is its greater durability. But this may easily be bought too dear. In the first place wagons get out of date. This was the case with the early railway wagons, which were soon superseded; and at the present moment a striking instance is afforded in the broad-gauge stock of the Great Western railway, which was built in the most durable style, but is now being in a great measure abandoned, or converted, at a heavy cost, to narrow-gauge. But apart from this, the ordinary life of a wagon is so hazardous, exposed to so many natural and unnatural shocks, that its average duration is much below what would be due to the ordinary processes of decay. On this point, as might be expected, opinions differ much, and statistics are hard to obtain. The engineer of one important railway stated that the number of wagons destroyed by accident was so small as not to be worth consideration. The engineer of another line, equally important, held that on an average wagons did not run above twelve years before coming to a violent end. Probably the truth lies between the two. At any rate there seems good reason to conclude that durability is by no means the most important point in the designing of such a structure as a railway wagon; and, in fact, so fully has this been realised by some leading authorities, that on the vast system of the Midland railway, for example, iron underframes are completely unknown.

Another point remains for consideration, viz., the scantling to be given to the headstocks, sole-bars, and middle bearers. In the diagram they are all 12 inches by 5 inches, and this is the scantling fixed by most of the leading railway companies for private wagons. At the same time dimensions much below these are not unknown. There are 6-ton wagons now running on the Swansea Vale railway whose sole-bars, &c., are only 9½ inches by 4½ inches. The Highland railway are content with 11 inches by 4½ inches, and the Caledonian railway with 10½ by 4½ inches. And it is specially to be remarked that those companies who insist most strongly upon the full dimensions in private wagons are yet often found to fall short of them in those they build for themselves. It was, in fact, admitted by a high authority that the full dimensions were not really necessary, but were retained to provide against the possible use by private builders of inferior materials. Even if requisite for the sole-bars and headstocks (on which the chief strains are brought), these dimensions would seem needless for the middle bearers. The reason for strengthening these was, no doubt, the fact that with ordinary draw-gear the whole strain of traction is brought upon them; but with continuous draw-gear this is not

the case, and then these middle bearers (especially if the bottom planks run across, not along the frame) have but little to do. In any case, the model wagon may be assumed to have sole-bars and headstocks of 11 inches by $4\frac{1}{2}$ inches scantling, and middle bearers and diagonals of 11 inches by 3 inches.

E. *Draw-gear.*—The draw-gear universally employed for wagons consists of a hook at each end of the truck, with a shackle and chain attached to it. This hook is welded on to the end of a bar ($1\frac{3}{4}$ inches round in general), which passes through the headstock and generally also through the middle bearer, and is made to bear against the latter by means of a nut and indiarubber washers. An improvement on this is the continuous draw-gear, which consists in uniting together the inner ends of the two drawbars so that they form one system, and the traction is obtained by the draw-hook in rear of the truck bearing against its headstock. It is clear that in the first case the body of the truck forms itself a link in the chain of traction, and the whole resistance of the hinder part of the train is transmitted through it as a tensile strain. In the continuous system, on the other hand, the drawbars form the chain, independently of the wagons, and the whole strain on any one of the latter is that due to its own resistance to traction, conveyed in the form of pressure which it is best adapted to resist. The disadvantage of the continuous system is its great weight and expense. The heavy drawbars, extending the whole length of the truck, do not add to its strength in the slightest degree, and the 'cradle,' or intermediate piece which connects the drawbars together is always cumbersome and costly. In view of this a system of continuous draw-gear has been designed, which is represented in Fig. 4. As will be seen, the indiarubbers are there contained in a wrought-iron case fixed upon the outside of the headstock: and the strain is transmitted through four $\frac{7}{8}$-inch rods, which at the same time act as the longitudinal ties of the underframe. The draw-hook terminates in a short shank which passes through the headstock to get an inside bearing. The advantages aimed at are: (1) A saving in weight and cost, since the ordinary tie-rods are dispensed with. (2) The avoidance of a weld in the drawbar, hence the risk which always attends a welded piece is absent. (3) The indiarubbers are outside the truck, and more easily accessible when required. (4) The strain is transmitted through four rods instead of one; and should one of these happen to be of inferior quality and give way, the other three would probably hold, at any rate till the wagon reached some place where the failure would be observed.

Before leaving the subject of drawbars a word may be said upon safety chains. These, which were once in general use, have been mostly abandoned, for it has been found that if a drawbar breaks the safety chains inevitably also break under the shock brought on them by the separating train. This, in fact, has so often been the case that their discontinuance is not to be wondered at; indeed, in more than one instance they have done actual harm by one of them holding while the other gave way, and thus getting the wagon across the line.

F. *Buffers.*—There would seem to be a growing inclination to abandon spring buffers—at least in mineral wagons: and this tendency, once begun, is likely to increase, since a wagon with spring buffers placed in a train of others having 'dead' buffers only is sure to fare badly. In the more expensive class of wagons, such as are built by railway companies, the wrought-iron buffer seems to be superseding the cast-iron.

The Midland railway and also the Great Western now build their wagons with a buffer system similar to that used for carriages. The buffer-heads are attached to long rods, which bear against the two ends of a large laminated spring laid horizontally across the underframe outside the middle bearer. The drawbar is widened out and a slot made in it, through which this spring passes, so that it acts against the traction as well as against the buffing strains.

G. *Body.*—The outside dimensions of the body are left in general to the judgment of the builder. The Taff Vale railway, however, specify that the capacity shall be between 240 and 245 cubic feet, and that the wheel base shall not be more than 5 feet 6 inches. This necessitates an exceedingly short and deep wagon. On other lines the wheel base is generally specified to be about 8 feet, and the length, especially in the North of England, is at least 13 feet, and often 14 feet or upwards. The Author considers the Taff Vale type, though perhaps exaggerated, represents much more nearly what should be aimed at. The advantages of short wagons are manifold. In the first place, they effect a considerable saving in weight and cost. The sheeting is of course nearly the same in any case if the cubic contents are the same; but the sole-bars, side rails, and diagonals are shortened, and so are the drawbars, capping irons, and longitudinal tie-rods. Secondly, short trucks are handier in themselves, and require smaller turntables. Thirdly, they make up into shorter and handier trains. This is of great importance when the enormous length of goods trains at the present day is considered, and also that such a train has usually to move its whole

length twice (first past the points and then over them) in order to get into a siding. Fourthly, a short truck cannot fail, as a long truck often does, by the 'hogging' of the sole-bars. Supposing a sole-bar to be uniformly loaded, and supported on axles 8 feet apart, it may be shown that it should not overhang more than 2 feet 10 inches at each end if the strain over the bearings is not to be greater than that at the centre; but, considering the weight of the headstock, buffers, and sheeting, &c., which are placed at the extreme end of the sole-bar, it would seem that 2 feet 3 inches is a more fitting limit. This would give a length of 12 feet 6 inches; and it is thought that this, with a width of about 7 feet 6 inches, and a depth of about 2 feet 9 inches, forms the most suitable body for an 8-ton wagon. If there are no end doors the two end planks may be curved with a rise of 5 inches, and then the depth at the sides need not exceed 2 feet 6 inches.

The thickness of the planking has also to be considered. In general that of the bottom is 2½ inches, and that of the sides either 2½ inches or 3 inches. The top edge is protected by a capping iron or flat bar. This bar is simply screwed down to the top plank, and does not add to the strength of the wagon in any way. It would appear feasible to transform this into a light angle-iron (say $2 \times 2 \times \frac{1}{4}$ inches) which should be bolted at each end to the corner plates (being let into the top plank throughout its length) and also to the inside knees wherever they occur. There would thus be formed a sort of light wrought-iron frame for the body, which would materially strengthen it, and the thickness of planking might then be reduced to 2 inches, or even less. The Caledonian railway even now employ planking only 1½ inch thick, strengthened by stanchions and a top rail, it is true; but this seems sufficient to prove that the thinner planking would not suffer unduly from wear and tear.

The inquiry is now concluded. For an 8-ton goods wagon, embodying the dimensions, &c., arrived at for the several parts, the tare weight would be about 3 tons 18 cwt., while the 8-ton wagons now running weigh from 4 tons 8 cwt. to 5 tons 10 cwt. Even so the proportion of tare to load (or of dead weight to paying weight) seems to be high; but the reasons stated at the commencement preclude the hope of the reduction being carried much further. It remains for the Author to express his obligations to several gentlemen connected with railways, both for valuable information and for drawings of wagons, many of which are exhibited: especially to Mr. Armstrong, of the Great Western railway; Mr. Beattie, of the London and South-Western railway;

Mr. Clayton, of the Midland railway; and Mr. Herbert Wallis, of the Grand Trunk railway of Canada. His aim throughout has been to raise points for discussion rather than to lay down authoritative rules, and with this understanding he now leaves the matter in the hands of the Institution.

The Paper is accompanied by a series of diagrams, from which Plate 9 has been compiled.

No. 1,472.—"Railway Rolling-stock Capacity, in relation to the Dead Weight of Vehicles." By WILLIAM ALEXANDER ADAMS, Assoc. Inst. C.E.[1]

THE Author, who has been since 1842 connected with the designing and manufacturing of railway rolling stock, desires in this Paper to draw attention to the apparent disproportion of dead weight to paying load, of freight and mineral wagons.

Forty years ago the family travelling-carriage, accommodating four inside, the dress chariot, carrying two, with hammercloth on the driver's seat and standboard for footmen behind, hung upon C-springs, and resting on a heavy under-carriage, weighed upwards of 1½ ton. But a few years before that date no other type of private carriage was in use, and for many years afterwards the only public hack conveyances were the old carriages of the nobility. The only means of public locomotion were the stage-coaches: omnibuses were unknown; and the hack cab on two wheels had not been seen. During the next twenty years the reduction of dead weight in proportion to paying load, and improvements in the construction of public and private common road vehicles, was open to the competitive intelligence of all, the public road being free to every one, and in 1861 broughams had been produced (Plate 10, Fig. 2) giving about the same accommodation and leg-room, and weighing only 6 cwt. 1 qr.

When railways were first opened, freight vehicles were fitted with buffing and drawing springs, and considerable attention was paid to details; but during the thirty ensuing years the types have gradually increased in dead weight; the use of spring buffers has been discontinued in coal and mineral wagons; and the increased dead weight necessitated heavier locomotives, and consequently heavier roads and heavier repairs to permanent way. The chief mineral moved in this country is coal, and the growth of that industry dates from the increase of business after the railway panic of 1848. The Author at that time built wagons, and let them out on hire for long periods, repairing and maintaining them at his own cost. The railway companies, who charged per ton for the load carried,

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[1] The discussion upon this Paper was taken in conjunction with the preceding one, and occupied portions of three evenings.

were strangely indifferent to the weight of the wagon, which they hauled full and empty free of charge. They had no regulations limiting dead weight; but as it was the Author's endeavour to construct wagons economical in first cost and in cost of repair, extending over terms of years, it was necessary, in order to have a low-priced wagon, to make a light one, the cost decreasing pretty much in the ratio of its weight. Then, as now, mineral wagons were built without buffing springs, and to avoid cost of repairs it was essential that the wagon should be strong. The Author departed from the ordinary type of construction, introducing plank bodies and the plan of framing shown in Plate 10, Fig. 1. Railway companies at that period limited the load to be carried to 6 tons. The soles and headstocks were of sound straight English oak, 12 inches by 4½ inches; cross bearers of the same, 11 inches by 6 inches; and the thrust framing, viz., the diagonals and the longitudinals, were of fir, the frame being held together by longitudinal and cross tie-rods. The floors were 7 inches by 2½ inches fir, and advantage was taken to increase the rigidity of the frame by laying the floor-boards longitudinally, rabbeting on to the headstocks flush with the top of the soles and headstocks, and spiking firmly to the flat diagonals. The frame thus panelled was practically solid. The drawbars were 1¾ inch in diameter at the inside of the head-stocks, and 1⅜ inch at the cross bearer, reduced to 1⅛ inch between the nuts.

The ordinary type of other builders' wagons was with soles 11 inches by 4½ inches; headstocks 13½ inches by 4½ inches; the two cross bearers, and diagonals and longitudinals all in oak, and the floors laid transversely, resting on the sole-bars, thus failing to utilise the flooring to strengthen the frame, and further necessitating an outside sill in oak, to cover the end of the floors and to carry the outside planking. Fir for thrust purposes was strongly condemned, and has since been interdicted on most railways. Pitch-pine is used throughout the United States for rolling-stock framing; and experiments conducted by the Author twenty-five years ago, at the suggestion of Mr. J. E. McConnell, M. Inst. C.E., proved that wood to be stronger, weight for weight, than any other in ordinary use. It has been adopted by the Great Northern Railway Company for the underframing and bodies of goods wagons.

The type Fig. 1 tared under 3 tons 5 cwt.; the wagons of other builders tared about 3 tons 15 cwt.; the difference in weight representing a difference in cost. The solidity of the panelled frame and the simplicity in construction of the other parts; the use of best cable iron for drawbars and chains; efficient elastic side-

springs, large grease capacity in the axle-boxes, and a well-selected mixture for brass bearings, economised repairs and maintenance. The railway companies, however, did not approve of these wagons, notwithstanding the economy caused by the saving of dead weight. From time to time regulations were issued by the London and North-Western, the Midland, and the Great Western Railway Company, all tending to enforce greater dead weight, but all varying—sometimes to a serious extent—causing considerable difficulty in the supply of wagons to private freighters. Some companies interdicted the use of side-chains; others insisted upon their application. At present the Great Western insist upon spring buffers; the London and North-Western and the Midland companies dispense with them.

For the purposes of the Paper the Author has collected various statistics from English, French, American, and other wagons, as shown in Plates 10 and 11, Figs. 3 to 35.

London and North-Western Railway.—Fig. 3, Plate 10, represents the older type, carrying 6 tons; and Figs. 4 and 5 the newer types, carrying 7 tons, the proportion of dead weight remaining about the same.

Great Northern Railway.—Fig. 6 represents the ordinary type of coal and goods wagon, carrying 9 tons, which compares favourably with other companies.

Midland Railway.—Fig. 7 represents the ordinary type of 6-ton goods wagon, and Fig. 8 the 7-ton. The proportion of dead weight is much in excess to that of other companies. A large traffic is done by this company in beer in barrels, and it would appear, from observations made by the Author, that the 6-ton wagons do not load more than about 3 tons of beer in barrels, and that most of the wagons work back empty, so that the Midland Company in their beer trade convey, full and empty, 12 tons 8 cwt. of dead weight for every 3 tons of paying load, thus receiving payment for less than one-fourth of all they move. Twenty years ago, the Author, as shown in Fig. 1, built 6-ton wagons taring 3 tons 5 cwt., and after a life of fifteen years a large number of these were hired by the Midland Railway Company for their beer and general traffic. But in the beer-carrying trade, and probably in others, the loss by traction of dead weight does not represent the whole loss, as with wagons of larger capacity and less dead weight, shunting-sidings, and wharf-room, would also be less.

North-Eastern Railway.—Fig. 9 represents the type in use, and does not differ from that adopted ten years back.

Great Western Railway.—Fig. 10 represents the older type, and

Fig. 11 the modern. In the latter it will be noted that 8 tons of paying load are carried upon wheels and axles weighing 1 ton 8 cwt. 2 qrs.; whereas on the North-Eastern (Fig. 9) the same load is carried on wheels and axles weighing 1 ton 16 cwt. There would thus seem to be a difference of 7 cwt. 2 qrs. in wheels and axles alone. The coal wagons of the Great Northern Company's standard type tare 5 tons 2 cwt., and convey a paying load of 9 tons.

Taff Vale Railway.—This company probably conveys a larger tonnage of coal per mile than any railway in the world, on a descending gradient to the shipping ports, and the empties uphill, practically all in freighters' wagons. The administration are fully alive to the question of dead weight, and their regulations will not permit the use of wagons exceeding a tare of 3 tons 17 cwt. for the conveyance of 8 tons of coal. Fig. 12 represents the usual type of 8-ton and tip coal wagon.

Great differences exist between wagons owned by wagon companies and other private owners, and there might be seen on the same sidings of the London and North-Western, working in the same class of trade, and apparently under similar conditions—the coal wagons J. S. Claye, 3320 (Fig. 13), Glo'ster Wagon Company, 6593 (Plate 11, Fig. 19), the one conveying 1 ton 9 cwt. 3 qrs. per ton of dead weight, and the other 2 tons 7 cwt. per ton of dead weight.

Upon a Great Western siding, working with a Birmingham Wagon Company's coal wagon of similar type and tare to Fig. 15, was a Broughton Coal Company's coal wagon No. 21 (Fig. 16), the one conveying 1 ton 13 cwt. 3 qrs. per ton of dead weight, the other 2 tons 3 cwt. 2 qrs. per ton of dead weight.

Fig. 17 represents a Metropolitan Wagon Company's coal wagon No. 11,446, one of a number lately supplied to a colliery on the Midland railway; it tares 4 tons 1 cwt., and has a capacity of 6 tons. Under the Midland Railway Company's present regulations for the construction of 6-ton wagons, it would probably be difficult to construct them of less tare. The difference of tare between the present example and wagons built twenty years ago by the Author (Fig. 1) is 16 cwt.; and presuming that one hundred wagons each work, full and empty, 200 miles per week, the Midland Railway Company have contracted to convey, free of charge for the life of the wagon, extending probably over twenty years, an excess of 832,000 tons per year for 1 mile.

Orleans Railway of France.—Figs. 20 and 21, Plate 11, represent the ordinary type of that company's wagons, adopting in all cases a capacity of 10 tons, thereby reducing the proportion of dead to

paying load, and effecting large savings in siding and wharfage accommodation.

Western Railway of France.—Fig. 22 represents the old type of 6-ton wagons, and Figs. 23 and 24 the type now adopted. The latter exhibits a fair proportion of dead weight to paying load as compared with other railways.

American Railroads.—With the exception of the bulk of the coal traffic of Pennsylvania, nearly all American freights and minerals are conveyed in eight-wheel bogie cars. In the opinion of the Author the dead weight of bogie cars as against paying loads must necessarily be greater than in ordinary four-wheeled wagons, as, practically, each bogie is in itself a wagon, and the dead weight of bodies built upon and made a part of the bogie would be considerably less than that of the independent body carried upon the bogie, which body is necessarily very heavy.

For coal the large bogie cars are inconvenient; and the Author believes that in practice nearly all the coal mined in Pennsylvania, and carried over the Pennsylvania and Lehigh Valley railroads, is conveyed in four-wheel wagons of somewhat rude construction (Fig. 25). They are without springs. The axle-boxes are carried in horizontal bars of hard wood, bolted to blocks under the soles of the wagon. Conveyed at slow speeds, these wagons appear to work well enough, but, judiciously constructed, the tare might be much reduced.

The light rails and imperfect road-bed of the bulk of the American railways precludes working such lines with the rigid engines and four-wheel wagons of European railways. The elastic American locomotive, without rigid side frames, and the low-wheeled car bogies with short wheel base, where the weight rests on the centre of the bogies and allows the wheels to lift and adjust themselves to the inequalities of the road, certainly go along, at from 12 to 16 miles an hour, in a surprising manner. Considerable reduction might, however, be effected in the weight of American freight cars, and the proportion of dead weight reduced from its present average of about ton per ton of paying load (Figs. 26, 27, 28).

The promoters and makers of the Denver and Rio Grande, and other 3-feet gauges, have looked well into the question of dead weight. The design and construction of the Denver and Rio Grande cars was placed in the hands of Messrs. Bilmeyer and Smalls, car-builders, of York, Pa., with excellent results, as shown in Figs. 29, 30. The promoters of these narrow-gauge lines claim as the advantage of their gauge the reduction of dead weight, a reduction just as readily to be effected on the 4-feet

8½-inch gauge by applying to the subject the same care and thought.

Soudan Railway of Egypt.—Fig. 32 represents the type of wagon designed by Mr. John Fowler, Past-President Inst. C.E., for a 3-feet 6-inch gauge. These wagons are constructed entirely of wrought iron, excepting the floors, which are of pitch-pine.

Festiniog Railway.—Figs. 33, 34, and 35 are the principal wagons upon that 2-feet gauge railway. It is to be noted that the tares are the extreme loads that are permitted to be carried, if the wagons will contain them.

The slate wagon (Fig. 33) does not usually load beyond 3 to 3½ tons of slate, and the coal wagon (Fig. 34) beyond 4 to 4½ tons of coal; but, allowing for that, the proportion of paying to dead weight is more economical on the cars of this railway than on those of any other. If 3 tons of paying weight to 1 ton of dead weight can be carried upon so inconvenient a gauge as the 2-feet, as good results should be looked for on the 4-feet 8½-inch gauge.

The Midland Railway Company have formally announced the intention to buy up all private coal wagons upon their system, and to supply freighters with wagons as well as locomotive power. If they do so, it is to be hoped they will, for increase of stock and replacements, endeavour to design wagons that shall carry 2½ tons and upwards of paying weight to 1 ton of dead weight. It appears that there are 28,805 wagons belonging to the company and 40,000 belonging to private owners—in round numbers, 69,000 wagons—none of which probably average in tare less than 4 tons 14 cwt. The Author has no reliable data upon which to base his assumption, but he understands that these wagons average 200 miles per week each, full and empty. Assuming the excess of dead weight to that which is required to be 1 ton per wagon, this represents a wasteful movement of 717,600,000 tons per annum moved 1 mile, which is equal to running thirty-four ordinary loaded mineral trains to Birmingham and back every working day in the year.

The Paper is accompanied by a series of diagrams, from which Plates 10 and 11 have been compiled.

[Mr. Adams

Mr. ADAMS said since the Paper was read he had been informed that the Pennsylvania Railroad Company now ran wagons of the class shown in Fig. 27, taring about the same, and carrying a load of 15 tons of coal. The use of small wagons on the Pennsylvanian main lines was continued, and the larger wagons were for the western branches. He wished it to be understood that he had no personal interest whatever in the matters under discussion. With regard to Plate 10, Fig. 1, it was not to be supposed that he considered it a perfect wagon. There were many things about it which, if he were designing a wagon for railways, he should not introduce. The wagon in question was intended to meet the requirements of the freighter, not those of the railway company. He never should have recommended a wagon without buffer springs or drawing springs, and he thought that such wagons should not be permitted on a railway. He had, however, built about five thousand of those wagons, which by their low tare had up to the present time saved the railways in conveyance about 500 million tons conveyed 1 mile. No doubt they gave a good deal of trouble to the companies for repairs. In the early days the manufacturers had not sufficient repairing stations, and the freighter rarely thought of sending a wagon for repair until it was almost falling to pieces. The owners who let them out on hire could not get them in for repairs, and wagons often continued running in a condition that ought not to have been permitted. As to dead weight, the difficulty was not in regard to the mechanical question, how to construct wagons of fair tare for the duty to be performed, but to direct the attention of the railway companies to the subject. For the past fifteen or twenty years these had looked favourably upon wagons that tared heavily, and wagon-owners and freighters had done the same.

He had not proposed to make any remarks upon the details of construction, but as another Paper had been read upon that subject, he could not leave it unnoticed. The wagon shown in Plate 9 would not pass the regulations of the Great Western Railway Company, which stated that no freighter's wagon should work upon the line unless it had buffer springs and drawing springs—an excellent regulation that ought always to be followed. The wagon would pass the Midland and the London and North-Western Companies, but wagons built under the regulations of the London and North-Western Company would not pass the Midland Company or the Great Western. The wheel was one of a type that had been out of use fifteen or twenty years. The standard wheels of the Great Western Company weighed 28 cwt. 2 qrs.; those of the North-Eastern 36 cwt. He could see no necessity for making wheels

so heavy. A solid wrought-iron skeleton of fair proportions would weigh about 9 cwt. the set, axles 6 cwt. 1 qr. If upon that skeleton $1\frac{3}{4}$-inch tires were put, all purposes of safety would be answered. He believed that the wheel and axle of the future were not those now in use. The future axle he thought would be a tubular one, 7 or 8 inches in diameter. He was of opinion that it was a mistake to make the wheel and then put the tire on the outside; and with steel, or more properly ingot iron, he believed it was possible to make the wheel in a solid piece, tire, skeleton, and nave. The tire would not then be in tension, and both tire and skeleton could be utilised. If these suggestions were adopted there would be an end of broken tires and broken axles. In theory a spring should be triangular in form, and in one plate that would deflect sufficiently without breaking or setting. In practice a spring should deflect about $1\frac{3}{4}$ inch with the weight of the body and load, and should be capable of deflecting say 5 inches in all without fracture or permanent set; then it would not matter whether it was 2, or 3, or 5 feet long, or whether there was one plate or fifty. In order to make a light spring the plates should be thickened. In setting out a spring, the proper course was to ascertain the greatest thickness of steel that would pass through 5 inches of space, and then add plate to plate until there were enough to carry the weight to be imposed upon them. He quite agreed in the view expressed by Mr. Browne, that oil was much superior to grease, and he considered the latter a barbarism. Grease had been continued in consequence of there being no effective means of oiling freighters' wagons. The only additional cost of oil-boxes was in the rings at the back making a joint upon the axle, and the cotton wool, or the springs put in to push the oil against the bottom of the axle. He had some time ago designed an oil axle-box for the time when it should be required by railway companies; it had never been used, but any one desiring to have an effectual and simple oil-box was welcome to the design. With regard to the axle-guards, his opinion was that they should be made strong. When wagons got off the road the axle-guards often bent and got out of shape, so that the wagons could not immediately be put on the line again, as they might be if strong axle-guards were used with the L iron wider than at present employed, Plate 9. A set of wheels and axles such as he had described would weigh 1 ton 5 cwt. 3 qrs., the springs 2 qrs. 2 cwt., and the oil-box 2 qrs. 2 cwt.; in making the box it would be worth while to resort to malleable cast iron. It was possible, he thought, to make thoroughly efficient wheels, springs and axle-box weighing 1 ton 9 cwt. 3 qrs. as against

1 ton 8 cwt. 2 qrs., the lightest description used by railway companies for wheels and axle alone. With reference to drawing and buffing springs, his opinion was that there was no method of buffing and drawing equal to that of laminated cross-springs; the plan was adopted thirty years ago, and there was nothing to supersede it. As to buffer-rods, he never could understand why they had not been made tubular. A buffer-rod 3½ inches in diameter, with a head worked carefully on, would be much lighter, stiffer and better than the ordinary form. He did not approve of the use of American oak cut from the log for wagon-making. It was poor in fibre, and consisted of about 20 per cent. of water. For 12-ton broad-gauge wagons he had usually stiffened the soles by flitching. The flitch was about 2 inches by 6 inches, and answered the purpose very well; there was no hogging, and the sole-bar was much stiffened.

Mr. Berkley was reluctant to detain the meeting from the practical remarks of carriage and wagon superintendents and traffic managers, who had more knowledge on the subject of the proportion between capacity and dead weight than other persons, though traffic managers might not know so much in regard to the details of mechanical construction. He ventured, however, to speak, because a few years ago he had prepared a document (pages 110–113) showing the proportionate weights, capacities, and bearing powers of railway wagons. The statement included wagons of all kinds, on sixteen 4-feet 8½-inch gauge lines, on seven 5-feet 6-inch lines, on one 5-feet line, and on one 5-feet 3-inch line. He had not given the maximum weight, as that only represented what could be put upon the vehicle under certain conditions of traffic. The capacity should not be represented by these figures, but by the floor area of a low-sided wagon, or the cubic contents of a high-sided or covered wagon; and his headings had been arranged accordingly. Having arrived at these points, he wished to ascertain where the bearing power was. He assumed that the frames would be strong enough in ordinary practice, but he found that the springs gave way, that the axles heated, and that the journals and the springs were therefore the parts which required special attention, in order to secure the bearing power being equal to the capacity represented by the floor area or the cubic contents of the wagons.

The abstract of gross averages gave the proportion of weight in tons of the wagons, to the floor area, to the cubic contents, and to other parts which really represented the bearing power. The form of the wagon should be determined by the nature of

its contents (as to whether they were bulky or heavy), and should also have some reference to the line itself. The curves on the railway would necessarily affect the construction, the length of the coupling, the use of bogie wheels and the like. Mr. Adams proposed to make wheels lighter than those used on some railways, which he complained of as being too heavy. He had taken a $1\frac{3}{4}$-inch instead of a 2-inch tire. Whether that was economical appeared doubtful. It was a pity that some standard of efficiency could not be adopted as a basis of comparison. With reference to the use of thick plates for springs, there could be no doubt that they gave greater bearing power than thin plates. Some years ago, however, the Great Western Railway Company almost invariably employed thick plates, and other companies had also tried them; but they were not now used, and he was at a loss to know the reason why. Experience had led to the use of thinner plates, which appeared therefore to be practically better than the others. In the comparison between wood and iron frames, no distinction had been made between the various kinds of wood, it being simply said that wood was cheaper and lighter. Taking teak, however, which was undoubtedly the best wood for such purposes, the difference in weight and cost was very small, but of course the difference would be affected by the varying market prices of the two articles. With oak or pitch-pine there would be a considerable advantage over iron both in regard to cost and weight. It was important that the wooden frames of wagons should be seasoned. Formerly the wood was properly seasoned, but in the present days of keen competition, when men were obliged to work for the lowest price, unseasoned wood was often employed, and hence the wagons were of inferior quality. He agreed as to the form of the axle behind the wheel; he had known many break from the shoulder at the back of the wheel. The shoulder was no doubt a great source of weakness, but that could be avoided.

STATEMENT of PROPORTIONATE WEIGHTS, CAPACITIES, A

Name of Railway.	Class of Vehicle.	Dimensions of Body. Inside. Length.	Inside. Width.	Inside. Height at the Centre.	Inside. Height at the Side.	Capacity. Area of the Floor.	Capacity. Cubical Contents.	Whee[ls]. Num ber o[f]
4 feet 8½ inches Gauge.		Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	
London and North-Western	Low sided, open	15 0	7 1½	0 9	0 9	107 0	..	4
	" "	15 0	7 1½	1 8	1 8	107 0	..	4
	" "	15 1	7 2	0 8½	0 8½	108 1	..	4
	" "	15 1	7 2	1 9	1 9	108 1	..	4
	" "	15 0	7 2	1 10	1 10	107 6	..	4
	Covered	12 10	6 6	6 2	5 6	83 5	426 9	4
	"	15 4	6 10	6 2	5 6	104 9	611 0	4
London and South-Western	High sided, open	15 0	7 2	5 3	3 3	107 6	456 10	4
	" "	14 8	7 0½	4 9½	2 9½	103 3	395 9	4
	" "	14 8	7 0	4 9½	2 9½	102 8	393 6	4
Great Northern	Covered	15 9	7 1½	6 1	5 6	112 2	654 4	4
	High sided, open	14 7	7 1	2 11	2 11	103 3	301 2	4
	" "	14 7	7 1	2 9	2 2	103 3	258 1	4
	" "	14 7	7 1	3 0	3 0	103 3	309 9	4
London, Brighton, and South Coast	Covered	16 0	7 1	5 11	5 8	113 4	661 1	4
	High sided, open	15 6	7 5	4 2	2 3	115 0	373 9	4
	" "	14 10½	7 4	5 9	3 0	109 0	481 5	4
Midland	Low sided, open	13 6	6 11	1 9	1 9	93 4	..	4
	" "	13 6	6 11	1 9	1 9	93 4	..	4
	" "	13 7	7 2	1 9	1 9	97 4	..	4
	Covered	13 0	6 7	6 2	5 5	85 7	499 4	4
	High sided, open	13 5	6 11	6 0	3 9	92 9	409 7	4
	" "	13 7	7 1	3 0	3 0	96 2	288 6	4
Great Western	Low sided, open	17 6	7 2	0 11	0 11	125 5	..	4
	" "	17 6	7 2	1 6	1 6	125 5	..	4
	" "	15 0	7 0	0 11	0 11	105 0	..	4
	" "	17 6	7 3	0 10	0 10	126 10	..	4
	Covered	17 4	6 10	5 6	5 1	118 5	631 6	4
	"	15 0	6 11	5 6	5 0	103 9	544 8	4
South-Eastern	Covered	14 0	7 3	6 6	6 2	101 6	642 10	4
	High sided, open	15 1	7 3	5 8½	2 8½	109 4	464 8	4
	" "	15 1	7 3	5 8½	2 8½	109 4	464 8	4
Great Eastern	High sided, open	15 8	6 10	4 0	2 3	106 9	338 0	4
	" "	15 7	7 6	4 0	2 3	116 10	370 0	4
Lancashire and Yorkshire	Low sided, open	15 7	7 2	0 8½	0 8½	111 8	..	4
	" "	15 7	7 2	1 6	1 6	111 8	..	4
	Covered	15 9	7 4	6 0	4 10	115 6	625 7	4
Manchester, Sheffield, and Lincolnshire	Covered	14 6	7 2	5 3	4 9	103 11	519 7	4
	High sided, open	15 7	7 1	2 6	2 6	110 4	275 10	4
London, Chatham, and Dover	High sided.	15 0	7 2	5 1	3 3	107 6	447 11	4
Pembroke and Tenby	Covered	15 0	7 0	6 9	6 1½	105 0	682 6	4
	High sided, open	13 8	6 11	3 4	2 11	94 6	299 3	4
Spalding and Bourne	Low sided, open	13 7	7 1	1 9	1 9	96 2	..	4
	Covered	13 6	6 11	5 3	4 9	93 4	466 8	4
Caledonian	Low sided, open	15 0	7 0	1 6	1 6	105 0	..	4
	Covered	13 8	6 6	6 0	5 6	88 10	510 9	4
	High sided, open	13 10	6 10	3 7½	2 9	94 6	307 1	4
Mid Wales	Covered	14 9	6 8	6 1	5 7½	98 4	581 9	4
	High sided, open	15 0	6 9	2 10	2 3	101 3	261 7	4
Mauritius	Low sided, open	14 0	7 0	0 9	0 9	98 0	..	4
	Covered	13 10	6 10	6 8	5 5	94 6	574 10	4
	"	13 10	6 10	6 8	6 0	94 6	598 6	4
	"	13 10	6 10	6 8	6 0	94 6	598 6	4
	High sided, open	14 0	7 0	3 2	2 8	98 0	285 10	4

Gross Averages 4 feet 8½ inches Gauge.

	Low sided	**Mean of 14 sets of vehicles for 7 railways**
	Covered	**" 17 " " 13 "**
	High sided	**" 20 " " 12 "**

N.B.—Each "set of vehicles" represents the number of the particular vehicle returned by one of the rail-

BEARING POWERS of WAGONS on SEVERAL LINES of RAILWAY.

Journals.			Springs.					Weight.	Averages.					
									Weight.	Capacity.		Journals	Springs.	
Length.	Diameter.	Product of the length × the diameter.	Distance centre to centre of Spring Shoes.	No. of Plates.	Width of Plates.	Thickness of Plates.	Product of the total thickness × the width.	Total weight when empty.	When empty.	Area of Floor.	Cubical Contents.	Product of the length × the diameter.	Distance from centre to centre of Shoes.	Product of the total thickness × the width.
In.	In.	In.	Ft. in.	No.	In.	In.	In.	T. c.	T. c.	Ft. in.	Ft. in.	In.	Ft. in.	In.
6	3	18	3 6	14	3	5 5/16	15 15/16	3 15						
6	3	18	3 6	14	3	5 5/16	15 15/16	4 0						
6	3	18	3 6	12	3	4 1/2	13 1/2	4 1	4 0 2/5	107 6 3/4	..	18	3 6	14 7/32
6	3	18	3 6	13	3	4 1/16	12 3/16	4 2						
6	3	18	3 6	12	3	4 1/2	13 1/2	4 4						
6	3	18	3 6	14	3	5 5/16	15 15/16	4 10	4 15 1/2	94 1	548 10 1/2	18	3 6	14 23/32
6	3	18	3 6	12	3	4 1/2	13 1/2	5 1						
7	3 1/2	24 1/2	3 2	11	3	4 1/4	12 3/4	5 18						
6	3	18	3 6	11	3	4 1/4	12 3/4	5 2	5 10 1/3	104 5 3/4	415 4 1/2	20 1/6	3 4 2/3	12 3/4
6	3	18	3 6	11	3	4 1/4	12 3/4	5 11						
8	3 1/4	26	3 6	14	3	5 1/2	16 1/2	5 6	5 6	112 2	654 4	26	3 6	16 1/2
8	3	24	3 6	12	3	4 9/16	13 11/16	5 0						
8	3	24	3 6	12	3	4 9/16	13 11/16	4 10	4 16	103 3	289 8	24 2/3	3 6	14 5/8
8	3 1/4	26	3 6	14	3	5 1/2	16 1/2	4 18						
8	3 1/2	28	4 3	9	3 1/2	3 15/16	13 25/32	6 2	6 2	113 4	661 1	28	4 3	13 25/32
8	3 1/4	26	3 6	13	3	4 3/4	14 1/4	5 11						
8	3 1/2	28	3 5	12	3	5 1/4	15 3/4	4 15	5 3	112 0	427 7	27	3 5 1/2	15
6	3	18	3 1 1/2	11	3	4 1/8	12 3/8	4 0						
6	3	18	3 2	12	3	4 5/8	13 7/8	4 13	4 9 2/3	94 8	..	18	3 1 5/6	12 7/8
6	3	18	3 2	11	3	4 1/8	12 3/8	4 16						
6	3	18	3 2	12	3	4 5/8	13 7/8	4 18	4 18	85 7	499 4	18	3 2	13 7/8
6	3	18	3 2	12	3	4 5/8	13 7/8	5 0						
8	3 1/2	28	3 2	12	3	4 1/2	13 1/2	5 14	5 7	94 5 1/2	349 0 1/2	23	3 2	13 11/16
7	3 1/2	24 1/2	3 6	11	4	4 1/4	17	5 6						
7	3 1/2	24 1/2	3 6	11	4	4 1/4	17	5 8						
7	3 1/2	24 1/2	3 6	10	4	4	16	4 7	5 1 1/2	120 8	..	24 1/2	3 6	16 3/4
7	3 1/2	24 1/2	3 6	11	4	4 1/4	17	5 5						
7	3 1/2	24 1/2	3 6	11	4	4 1/4	17	5 18						
7	3 1/2	24 1/2	4 3	19	3	7 1/4	21 3/4	5 4	5 11	111 1	588 1	24 1/2	3 10 1/2	19 3/8
8	3 1/4	26	3 4	12	3	4 9/16	13 11/16	5 5	5 5	101 6	642 10	26	3 4	13 11/16
8	3 1/4	26	3 4	12	3	4 9/16	13 11/16	5 0						
8	3 1/4	26	3 4	12	3	4 9/16	13 11/16	5 10	5 5	109 4	464 8	26	3 4	13 11/16
8	3 1/4	26	3 6	11	3 1/2	4 1/8	14 7/16	4 17						
8	3 1/2	28	3 8	11	3 1/2	4	14	5 2	4 19 1/2	111 9 1/2	354 0	27	3 7	14 7/32
6	3	18	3 6	12	3	4 1/2	13 1/2	4 3						
6	3	18	3 6	12	3	4 1/2	13 1/2	4 5	4 4	111 8	..	18	3 6	13 1/2
6	3	18	3 6	12	3	4 1/2	13 1/2	4 18	4 18	115 6	625 7	18	3 6	13 1/2
8	3 1/4	26	3 6	12	3 1/2	4 5/8	16 3/16	5 3	5 3	103 11	519 7	26	3 6	16 3/16
8	3 1/4	26	3 6	12	3 1/2	4 5/8	16 3/16	4 12	4 12	110 4	275 10	26	3 6	16 3/16
8	3 1/2	28	3 6	12	3	4 1/2	13 1/2	5 8	5 8	107 6	447 11	28	3 6	13 1/2
7	3 1/2	24 1/2	3 3	10	3 1/2	3 3/4	13 1/8	5 12	5 12	105 0	682 6	24 1/2	3 3	13 1/8
6	3	18	3 0	11	3	4 1/8	12 3/8	3 19	3 19	94 6	299 3	18	3 0	12 3/8
6	3	18	3 2	11	3	4 1/8	12 3/8	4 13	4 13	96 2	..	18	3 2	12 3/8
6	3	18	3 2	11	3	4 1/8	12 3/8	4 16	4 16	93 4	466 8	18	3 2	12 3/8
8	3 1/4	26	4 3 1/2	10	4	3 7/8	15 1/2	5 5	5 5	105 0	..	26	4 3 1/2	15 1/2
8	3 1/4	26	3 2	10	3 3/4	5	18 3/4	5 15	5 15	88 10	510 9	26	3 2	18 3/4
8	3 1/4	26	3 3	10	4	5	20	4 10	4 10	94 6	307 1	26	3 3	20
7	3 1/4	22 3/4	3 4	12	3	4 5/8	13 7/8	5 5	5 5	98 4	581 9	22 3/4	3 4	13 7/8
7	3 1/4	22 3/4	3 4	12	3	4 5/8	13 7/8	4 10	4 10	101 3	261 7	22 3/4	3 4	13 7/8
9	3 1/4	29 1/4	3 6	11	3	4 3/16	12 9/16	4 2	4 2	98 0	..	29 1/4	3 6	12 9/16
9	3 1/4	29 1/4	3 6	11	3	4 3/16	12 9/16	5 13						
9	3 1/4	29 1/4	3 6	11	3	4 3/16	12 9/16	5 15	5 17 2/3	94 6	590 10	29 1/4	3 6	12 9/16
9	3 1/4	29 1/4	3 6	11	3	4 3/16	12 9/16	6 5						
9	3 1/4	29 1/4	3 6	11	3	4 3/16	12 9/16	4 15	4 15	98 0	285 10	29 1/4	3 6	12 9/16
..	..	..	..	..	..	..	..	..	4 10 1/4	104 9 1/10	..	21 9/14	3 6 1/28	14
..	..	..	..	..	..	..	..	..	5 6 1/16	101 4	582 5 1/2	23 6/13	3 5 15/16	14 19/32
..	..	..	..	..	..	..	..	..	4 18	102 9 1/2	348 1 1/3	24 1/6	3 4 1/4	14 1/2

y companies, for whom the same has been manufactured, or by the wagon-maker by whom it has been manufactured.

STATEMENT of PROPORTIONATE WEIGHTS, CAPACITIES …

Name of Railway.	Class of Vehicle.	Dimensions of Body. Inside. Length.	Inside. Width.	Inside. Height at the Centre.	Inside. Height at the Side.	Capacity. Area of the Floor.	Capacity. Cubical Contents.	Whe… Num… o…
5 feet 6 inches Gauge.		Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	Ft. in.	
Great Indian Peninsula . . .	Low sided, open .	18 7	8 1	1 2½	1 2½	150 3	..	4
		18 7	8 1	2 0	2 0	150 3	..	4
		16 8	8 1	1 2½	1 2½	134 8	..	4
	Covered	16 6	7 8	6 6	5 3	124 6	736 7	4
		16 6	7 8	6 6	5 3	124 6	736 7	4
	Cotton van . . .	23 6	9 0	8 0	6 8	211 6	1,551 0	4
		19 6	9 0	8 0	6 8	175 6	1,287 0	4
	High sided, open .	16 8	7 8	4 11	3 1½	127 9	521 8	4
		16 8	7 8	4 11	3 1½	127 9	521 8	4
Delhi	Covered	15 5½	7 9½	7 2	6 4	120 5	812 10	4
	„	15 4	7 8	7 2	5 6	117 6	744 2	4
	„	15 6	7 10	7 4½	6 5	121 5	839 9	4
	High sided, open .	15 6	7 8	5 0	3 6	118 10	505 0	4
	„ . . .	15 8	7 10	5 0	3 6	122 9	521 8	4
Bombay and Baroda	Covered	15 4	7 8	7 1	5 2	117 6	724 7	4
Eastern Bengal	„	18 3	8 0	7 5	7 0	146 0	1,058 6	4
	High sided, open .	15 7	7 10½	3 1½	2 7½	122 9	358 0	4
Tudela and Bilbao	Covered	15 10	8 5	7 0	6 10½	133 3	932 9	4
	High sided, open .	14 8	7 8	4 9	3 0	112 5	440 3	4
Ceylon	Low sided, open .	15 7	7 9	1 1	1 1	120 9	..	4
	Covered	15 5	7 7	6 3	5 10	117 0	711 9	4
	„	14 5	7 7	6 3	5 10	109 4	665 1	4
	High sided, open .	15 7	7 9	2 11½	2 11½	120 9	357 1	4
Santiago and Valparaiso . . .	Low sided, open .	15 7	8 1	2 4	2 4	126 0	..	4
	Covered	15 4	7 9	8 0	7 2	118 10	901 1	4
Gross Averages of the 5 feet 6 inches Gauge, excepting the G. I. P.								
	Low sided, open	**Mean of 2 sets of vehicles for 2 railways**						..
	Covered . . .	**„ 9 „ „ 6 „**						..
	High sided, open	**„ 5 „ „ 4 „**						..
MIXED GAUGES.								
Irish . . . 5 feet 3 inches	Covered	13 3	7 3	6 10	5 1	96 1	576 6	4
	„	15 0	7 6	6 10	5 1	112 6	675 0	4
	„	13 4	7 3	6 10	5 0	96 8	572 0	4
	High sided, open .	13 8	7 2	3 3	2 9	98 0	294 0	4
Russian . . . 5 feet 0 inches	Covered	20 10	8 5	7 10	7 4	175 4	1,329 7	4
		20 7	8 7	7 4	6 11½	176 8	1,266 1	4
	High sided, open .	20 8	8 8	5 8	3 3½	179 1	805 10	4

In Tons, Cwts.—Feet, Inches.

Abstract of Gross Averages.			Weight Empty.	Area of Floor.	Cubical Contents.	Journals. Area. Product of the length × the diameter.	Springs. Length. Centre to centre of Spring Shoes.	Springs. Section Area. Width × the total thickness.
			T. cwt.	Ft. ins.	Ft. ins.	Ins.	Ft. ins.	Ins.
4 ft. 8½ ins. gauge.	Low sided .	Mean of 14 sets of vehicles on 7 railways	4 10½	104 $9\frac{1}{16}$	..	$21\frac{9}{14}$	3 $6\frac{5}{28}$	14
	Covered . .	„ 17 „ „ 13 „	5 $6\frac{3}{13}$	101 4	582 5½	$23\frac{6}{13}$	3 $5\frac{11}{16}$	14[illegible]
	High sided .	„ 20 „ „ 12 „	4 18	102 9½	348 1⅜	24⅝	3 4½	14⅜
G. I. P. 5 ft. 6 ins. gauge.	**Low sided**	**Mean of 3 sets of vehicles . .**	**5 12½**	**145 0½**	**..**	**30**	**3 6**	**14[illegible]**
	Covered .	**„ 2 „ „ . .**	**5 16**	**124 6**	**736 7**	**30⅜**	**3 6**	**14[illegible]**
	High sided	**„ 2 „ „ . .**	**5 11**	**127 9**	**521 8**	**30⅜**	**3 6**	**14[illegible]**
	Cotton . .	**„ 2 „ „ . .**	**6 9½**	**193 6**	**1,419 0**	**30⅜**	**3 6**	**16[illegible]**
5 ft. 6 ins. gauge, excepting the G. I. P.	Low sided .	Mean of 2 sets of vehicles on 2 railways	5 1	123 4½	..	28½	3 6	15[illegible]
	Covered . .	„ 9 „ „ 6 „	6 10½	124 9	850 6	28½	3 5½	15
	High sided .	„ 5 „ „ 4 „	5 3½	119 2½	417 2	$28\frac{7}{16}$	3 4½	14[illegible]

N.B.—Each "set of vehicles" represents the number of the particular vehicle returned by one of the railw…

...aring Powers of Wagons, on several Lines of Railway.

Journals.		Springs.					Weight.	Averages.					
								Weight.	Capacity.		Journals	Springs.	
Diameter.	Product of the length × the diameter.	Distance centre to centre of Spring Shoes.	No. of Plates.	Width of Plates.	Thickness of Plates.	Product of the total thickness × the width.	Total weight when empty.	When empty.	Area of Floor.	Cubical Contents.	Product of the length × the diameter.	Distance from centre to centre of Shoes.	Product of the total thickness × the width.
In.	In.	Ft. in.	No.	In	In.	In.	T. c.	T. c.	Ft. in.	Ft. in.	In.	Ft. in.	In.
3¼	29¼	3 6	12	3	4⅞	14⅝	5 17						
3¼	31¼	3 6	13	3	5⅛	15⅜	5 18	5 12¾	145 0¾	..	30	3 6	14⅞
3¼	29¼	3 6	12	3	4⅞	14⅝	5 3						
3¼	31¼	3 6	13	3	5¼	15¾	5 17	5 16	124 6	736 7	30⅜	3 6	14 11/16
3¼	29¼	3 6	12	3	4⅞	14⅝	5 15						
3¼	31¼	3 6	14	3	5½	16½	6 14	6 9¼	193 6	1,419 0	30⅜	3 6	16⅛
3¼	29¼	3 6	14	3	5¼	15¾	6 5						
3¼	31¼	3 6	13	3	5⅛	15⅜	5 8	5 11	127 9	521 8	30⅜	3 6	14 11/16
3¼	29¼	3 6	12	3	4⅞	14⅝	5 14						
3¼	29¼	3 6	13	3	5	15	6 15						
3¼	29¼	3 6	13	3	5	15	6 15	6 9	119 9½	798 11	29¼	3 6	15
3¼	29¼	3 6	13	3	5	15	5 17						
3¼	29¼	3 3	13	3	5	15	5 5	5 5	120 9½	513 4	29¼	3 3	15
3¼	29¼	3 3	13	3	5	15	5 5						
3¼	31½	3 6	10	3	4	12	6 5	6 5	117 6	724 7	31½	3 6	12
3¼	29¼	3 6	14	3	5½	16½	7 0	7 0	146 0	1,058 6	29¼	3 6	16½
3¼	29¼	3 6	13	3	5¼	15¾	5 0	5 0	122 9	358 0	29¼	3 6	15¾
3¼	26	3 4	14	3	5⅜	16⅛	6 10	6 10	133 3	932 9	26	3 4	16⅛
3¼	26	3 4	13	3	5	15	5 5	5 5	112 5	440 3	26	3 4	15
3¼	29¼	3 6	10	3½	4	14	4 14	4 14	120 9	..	29¼	3 6	14
3¼	29¼	3 6	10	3½	4	14	6 5	6 4	113 2	688 5	29¼	3 6	14
3¼	29¼	3 6	10	3½	4	14	6 3						
3¼	29¼	3 6	10	3½	4	14	5 5	5 5	120 9	357 1	29¼	3 6	14
3¼	28	3 6	12	3½	4⅝	16 3/16	5 8	5 8	126 0	..	28	3 6	16 3/16
3¼	28	3 6	12	3½	4⅝	16 3/16	6 15	6 15	118 10	901 1	28	3 6	16 3/16
..	..	..	..	..	..	..	..	5 1	123 4½	..	28½	3 6	15 1/16
..	..	..	..	..	..	..	..	6 10¼	124 9	850 6	28¼	3 5¼	15
..	..	..	..	..	..	..	..	5 3¼	119 2½	417 2	28 1/16	3 4¾	14 15/16
3	18	3 6	13	3½	5	17½	5 10						
3¼	19½	3 4	13	3½	5	17½	5 18	5 14⅓	101 9	607 10	20½	3 3⅓	17⅛
3	24	3 0	12	3½	4¾	16⅝	5 15						
3	18	3 6	13	3½	5	17½	5 0	5 0	98 0	294 0	18	3 6	17½
3¼	23	3 6	8	3	4	12	5 15	6 5	176 0	1,297 10	22 1/16	3 6	12
3¼	21⅞	3 6	8	3	4	12	6 15						
3¼	21⅞	3 6	8	3	4	12	5 5	5 5	179 1	805 10	21⅞	3 6	12

In per cent. taking G. I. P. as 100.						Proportions.				
			Journals.	Springs.						
Weight empty.	Area of Floor. (Square.)	Cubical Contents. (Cubical.)	Area.	Length.	Sectional Area.	Of Weight in tons to Floor Area.	Of Weight in tons to Cubical Contents.	Of Weight in tons to Area of Journal.	Of Weight in tons to Length of Springs.	Of Weight in tons to Sectional Area of Springs.
T. cwt.	Ft. ins.	Ft. ins.	Sq. ins.	Ft. ins.	Sq. ins.					
68·59	72·22	..	72·21	100·40	95·72	1/23·07	..	1/4·73	1/·77	1/3·14
81·56	81·39	79·07	77·23	98·97	99·70	1/19·98	1/109·68	1/4·41	1/·65	1/2·76
88·28	80·36	66·74	81·74	96·42	97·05	1/20·98	1/71·04	1/5·06	1/·68	1/2·98
100·	100·	..	100·	100·	100·	1/25·75	..	1/5·32	1/·62	1/2·59
100·	100·	100·	100·	100·	100·	1/21·46	1/126·99	1/5·23	1/·60	1/2·55
100·	100·	100·	100·	100·	100·	1/23·01	1/93·99	1/5·47	1/·63	1/2·66
..	..	..	..	..	..	1/20·90	1/219·31	1/4·69	1/·55	1/2·49
89·65	85·05	..	95·41	100·	103·20	1/24·45	..	1/5·66	1/·60	1/2·36
112·50	100·20	115·46	95·06	99·20	101·27	1/19·12	1/130·34	1/4·57	1/·58	1/2·29
93·48	93·27	79·96	93·59	97·00	100·21	1/22·97	1/80·33	1/5·46	1/·65	1/2·86

...panies, for whom the same has been manufactured, or by the wagon-maker by whom it has been manufactured.

Mr. Benedict wished to call attention to the cylindrical iron wagons at present used on the Eastern Bengal railway. They weighed about 6 tons, were 10 feet in diameter, and were built to carry 10 tons, but as a rule they were only loaded with 7 tons of jute in bales. They had lately been tested in an accident that happened on the line just before he left India. The train was composed of twenty-nine vehicles, exclusive of the engine and tender, and there were eight empty cylindrical wagons in the fore part of the train. When the train left the line, owing to a rail having been taken out, it was travelling at a speed of 18 miles an hour, and it was brought up in a distance of 100 feet. Part of the train, 350 feet long, was jammed into a space of about 100 feet. All the timber wagons in front of the cylindrical wagons, some loaded and some empty, were smashed, as was also one behind the cylindrical wagons. The cylindrical wagons themselves were so little damaged, that with a few repairs done on the spot, they were run down on their own wheels and axles two days afterwards to the workshops, which were 40 miles distant.

Mr. Grover hoped some explanation would be given by traffic managers or others of the interesting diagrams exhibited, and the extraordinary differences represented by them. Comparing the wagons of the Western Railway of France, showing a capacity per ton of dead weight of 2 tons 11 cwt. 1 qr., with the wagons of the London and North-Western, the Great Northern, and the Midland, which varied from 1 ton 10 cwt. upwards, it was evident that one or the other must be wrong, and he trusted some explanation would be given of differences so remarkable. Wagons nearly always failed by hogging. The nearer together the wheels were placed the greater was the amount of hogging, and the more the wheel base was increased the greater was the stability of the wagon. As it followed that the stability of the vehicle would be as the square of the span, it was in many respects important to keep the wheels as far apart as possible, but if too far apart it was difficult to get round curves, which were every day becoming smaller and smaller, so that there were two opposite requirements to be considered. The question was whether some bogie arrangement was not preferable. The results shown from America were not such as to give an exalted idea of the merits of bogies, and but for the redeeming features exhibited in one narrow-gauge line, it would seem that the less one had to do with them the better. He had endeavoured so to arrange a wagon as to be able to put the wheels at the two extremities to get the maximum amount of rigidity, and at the same time to adapt the bogie to a four-wheeled

vehicle. It was remarkable that so much had been done to apply bogies to engines, while scarcely any trouble was taken to apply radiating axles to wagons or carriages, yet there was, in the case of an ordinary train, ten times the weight behind the engine that there was in the engine itself, and though there was not actually so great an impact upon each particular wheel, yet in the aggregate there was considerably more weight passing over the rails. The late Mr. Stephenson used to say, that more injury was done by bad rolling stock than by heavy engines, and no doubt that was the case. The inequality of the blows coming upon the vehicles in passing round a curve, however small, was a matter worthy of observation. There appeared with rigid stock to be no means of getting a fair shock either through the drawbar or on the buffer-heads. He maintained that it ought to be possible to radiate the extremities of the vehicles, the drawbar, the buffer, and the axle, so as to receive a fair blow upon them in whatever position they might be; and until that was done it would be found impossible to reduce the enormous dead weights represented on the English lines.

Mr. C. Douglas Fox thought it surprising that so practical a people as the Americans should have gone on for so many years with such an unsatisfactory state of things in reference to the proportion of paying load to dead weight. While the English results were bad, the American were even worse. This had probably resulted from the introduction of the bogie truck in the first instance, leading to the use of long wagons, which had been almost universally adopted until the present time. The able managers of the Pennsylvania Railroad Company had seen the objections to that class of wagon, and had of late years taken some steps to modify it, and the result had been the introduction of shorter wagons. It had fallen to his lot to investigate the subject in connection with a railway in Canada, and it was found that the practical inconvenience of a long wagon, apart from the question of dead weight, was most serious, not only from the effect of the large amount of empty running that must take place with wagons of large capacity, but also from the fact that they were most inconvenient for shunting at roadside stations. Many such wagons were so heavy that it was impossible to shunt them without horses, or a locomotive at each station. The consequence had been that, whereas it was of importance in many cases to have local sidings for the service of small traffic, it became practically difficult to deal with it at all. In Canada, instead of adopting the American system of very long wagons, he had employed more

I 2

moderate lengths, and beneficial results had arisen from the change. There could be no doubt that the smaller the size of the wagon to carry a fair load in proportion to the expense involved (for whatever the size, the cost of the wheels, axles, springs, and other fittings had to be dealt with), the more likely it was to be a handy and useful vehicle. With regard to the proportion of dead weight, that must greatly depend upon the character of the materials to be carried. The figures in the diagrams were deceptive, unless a statement was given (as it was in a few instances) of the materials conveyed in the wagons. With regard to the Denver flat cars, he could not see how it was possible to construct a flat car, which would have such a small proportion of dead weight to paying load as was represented, unless it was loaded with something of a compact and heavy nature. It would be, of course, easy to make a wagon that would weigh about one-fourth of the gross weight, if it was to be used for something very compact. In a case within his own experience, where ironstone was conveyed in pit-tubs, having the roughest possible usage, running underground at the rate of 12 miles an hour, and constantly coming off the line, so that it was important to make them thoroughly strong, no difficulty was found in keeping the dead load down to one-fourth of the gross weight. That, however, could not be done if the load consisted of wool or any other light material, as the wagon had then to be designed far too strong for its load, in order to withstand the shocks to which it would be subjected. In the present day, when so much shunting was done by hand, the importance of breaks could hardly be over-estimated. He believed the most practical break at present in use was that fitted to the newest pattern of the North-Eastern wagons. It was fixed with a handle across the end of the wagon, so that a man walking by the side could put it on while the wagon was running, or he could stand on the buffer and apply it with his feet. Good wagons were often much deteriorated by the fact, that little thought had been given to the question of the break. He thought one point had been lost sight of in regard to the construction of wagons, namely, the importance of so constructing them that they could be easily repaired. He was much surprised to find from Mr. Adams's Paper that on one railway iron wagons were again being generally adopted. No doubt there were circumstances in which they were really required, as, for instance, when hot calcined ironstone was carried, but he was at a loss to see how, in ordinary cases, they could possibly be economical. They might be, in one sense, more durable, but the cost and trouble of repairing them were very great. With refer-

ence to the underframes, he thought one could hardly do better than adopt a combined arrangement of wrought iron and timber, his preference as regards timber being given to thoroughly good English oak. Having had many years' experience in the use both of grease and oil in various climates, he gave his decided preference to the latter, and saw no reason why there should be any serious difference in the cost of axle-boxes on the two systems.

Mr. CLAYTON said it was admitted on all sides that it was desirable to keep the rolling stock as light as possible; nevertheless it should not be too light. The 6-ton wagon that had been described was too heavy for the load it carried; while the 10-ton load was, he believed, too heavy for a wagon in work, it so strained and broke it down that it was out of traffic more days in the year, requiring more repair, than a lighter one. He thought an 8-ton wagon was the most economical and the best, at all events for carrying coal. It was impossible to make a 6-ton wagon light in proportion to the load it carried, as it had to stand the same strain in starting and stopping and shunting as a wagon constructed to carry 10 tons. It might be next an engine, or next two engines, with forty heavy loaded wagons. It had, therefore, to be built so that it could bear a great deal of knocking about, and it was impossible to get the same tare in proportion to the load it had to carry. It was desirable to keep the weight of the ironwork as light as possible. Taking a solid wrought-iron wheel with a single spoke and a solid boss, it could be made very light—about 2 cwt. a pair lighter than an ordinary wheel with a double spoke. Instead of having a double spoke $3\frac{1}{2}$ inches by $\frac{3}{4}$ inch, equal to $3\frac{1}{2}$ inches by $1\frac{1}{2}$ inch, and a cast boss 13 inches in diameter, a solid wrought-iron spoke 1 inch thick and 3 inches wide, halfway between the boss and the periphery of the wheel, the boss being 8 inches in diameter, could be made much lighter, and, by those who had the proper tools, at little, if any, additional expense. It was a mistake to put on the tires too thin. If $1\frac{3}{4}$ inch thick, when worn down to 1 inch they had to dispensed with. To re-tire such a pair of wheels with tires 2 inches thick would cost about £8, so that every $\frac{1}{8}$ inch in such a case was worth £1. With tires $1\frac{3}{4}$ inch thick there would be the same expense for labour, the only saving would be $12\frac{1}{2}$ per cent. in material, but the loss in wear would be 25 per cent., and that on the most valuable part of the tire. Bearing springs should not be made too stubborn, their object being to take the jar and jerk off the load. They had been made of various shapes, such as spiral and volute, and they had been used in wagons rather extensively. It was not always

known what a wagon had to stand in such cases. He had occasionally tried experiments by putting such springs under the guards' vans, and the guards soon found out the difference. The spiral and volute springs had had the effect of putting out the lamps in the vans, and this he thought was sufficient to show, apart from the testimony of the guards (who did not like the introduction of anything new), that such springs ought to be dispensed with. Wagons should be constructed in accordance with what they could endure in actual work rather than in reference to the particular load to be carried. There was a considerable difference between railway companies' wagons and freighters' wagons, but as the latter were chiefly dealt with in the Papers, he would confine his remarks to them. He was glad to find that Mr. Adams did not recommend the type of wagon built by him some years ago. He was quite sure, if Mr. Adams were a carriage superintendent of a railway company, he would not build such a class of wagon. Wagon-builders and owners, or freighters, could afford to have lighter and cheaper wagons than a railway company, because the cost of maintenance partly fell upon the companies. If a wagon was damaged in transit the company repaired it, and if it were destroyed in an accident the company rebuilt it. This was rather a serious matter when it was remembered that 20 per cent. of the wagons were rebuilt before they had reached the age of ten years. It could hardly be supposed that so large a proportion would wear out by natural decay. No doubt most of them came to a premature end.

With regard to the use of oil and grease, it was stated in Mr. Browne's Paper that the cost of oil axle-boxes only exceeded by about £2 per set the cost of grease-boxes, and that that amount would soon be repaid. It could hardly be repaid in a short time, since £2 would pay for the grease used by a wagon in ten years. The expense of altering the wagons in which grease was used would at any rate put any change out of the question for some years to come. He could not see that there was any more friction with grease than with oil. The fastest trains, and those having the longest trips, in England ran with grease. The London and North-Western, the Great Western, and the Midland companies had experimented on the subject for years, and they had returned to the use of grease for all main-line trains. Three years ago the Midland Company had about fifteen hundred carriages working with oil, using £3,000 worth of oil per annum. They had been fitted up within three or four years with the best known oil-boxes, yet it was found that in the carriages running with oil there were four times as many hot axle-boxes as there were in the carriages

running with grease. Now that the company had returned to the use of grease, only one-fourth the number of axle-boxes became heated as compared with those that were heated three years ago. The best oil was used that could be obtained in the market. Having been for many years on the Great Western railway, he knew something of the use of iron underframes for wagons, and he believed they were not the best. No doubt they had greater tensile strength than wood, but in case of collision or of running off the line, or of shunting, the frames were so buckled and bent as to give a great deal of trouble in repairs. He believed nearly all the Midland Company's wagons had laminated spring buffers, now employed by most of the leading railway companies. The weight of the wagon was increased by them to the extent of about 6 cwt., and the cost was increased by about £2 5*s.* per wagon; but they effected a considerable saving in regard to both the wagon and the goods carried. Some goods were fragile and valuable, and if damaged in transit the railway companies had to pay for them, so that it was considered to be more economical to go to a little additional expense in order to prevent those losses. Such buffers also were the cheapest to maintain, costing only 2*s.* 6*d.* per wagon per annum, whereas other elastic buffers usually cost about 10*s.* per annum. On one or two of the leading lines of railway, where only a portion of the stock was fitted with elastic buffers, the cost of buffer repairs alone was £10,000 or £15,000 a year. The Midland Company had, up to about three years ago, twenty-five thousand 6-ton wagons. During the last three years the Company had only built 8-ton wagons, which were 18 inches longer than the others, with stronger axles and springs, but precisely of the same weight as the 6-ton wagons.

Mr. Bruce said a great deal of attention had been paid to the proportion of paying load to dead load, and a great deal of ignominy had been heaped upon railway companies under the impression that they were making wagons and carriages heavier than necessary. He thought some of the discrepancies were due to the different circumstances under which the loads were carried. It was stated that the Taff Vale Company carried a large paying load compared with the dead weight of the wagon, while the Midland carried a small paying load. But the circumstances were different in the two cases. Most of the long railway lines had to carry their loads at great speeds, and they therefore required heavier wagons to bear the strain and shock incident to the journeys. The Festiniog railway appeared tc carry a large paying load compared with the size of the wagons,

but the circumstances were different (the goods conveyed being slates), and he did not think the proportion of dead to paying load at all applied to wagons made to carry the ordinary class of merchandise. He believed that as a rule wagons could not wisely be made to carry on the average more than from $1\frac{1}{2}$ to $1\frac{3}{4}$ time its dead load. The remarks made as to the disadvantage of thin tires would, he thought, apply with equal force to solid wheels, the repairs of which would be more costly than the repairs of the common wheels. It had been stated that the friction with oil axle-boxes was only 3 lbs. per ton, and that the friction with grease axle-boxes was 9 lbs. It was impossible to conceive that that was the actual condition of things in practice, though it might have been the case in some solitary exceptional experiment, and he was glad to hear the remarks of Mr. Clayton on the subject. With regard to large hollow buffer-rods, as suggested by Mr. Adams, he thought there were difficulties in the way of their employment—the cutting away of the headstock through which the rod had to pass, as well as the cross timbers of the carriage, was an interference with the strength, which would have to be supplied in some other way if adopted. He agreed that sole-bars could now be made with iron of the same weight and at the same cost as with wood. It might be conveniently done in a trough form, making the internal cross-framing of timber. He would rather combine wood and iron in that way than put (as Mr. Adams suggested) an L piece on the outside of the sole-bar. With regard to the cylindrical wagons on the Eastern Bengal railway, no one had heard of their being used anywhere else. They might do very well for collisions, but they were badly adapted for carrying loads. Hogging generally arose from the wheel base being too small compared with the size of the wagon. If the length of the wheel base was made $\frac{6}{10}$ths of the length of the wagon there would not be much tendency to hog. The form alluded to by Mr. Grover, with a sort of radial frame, he had himself used, and for carriages it worked very well, especially for going round sharp curves. He could not but express his admiration of Mr. Adams's perseverance, energy, and care in preparing the diagrams. He had himself, some years ago, prepared a short statement of the different sizes, weights, &c., of wagons, as follows. (See next page.)

He had ascertained that the maximum load upon the journals of carriages or wagons was about 2 cwt. per square inch of journal. He did not think that any plan for a uniform size and description of wagon would answer the purpose, and it would certainly stop

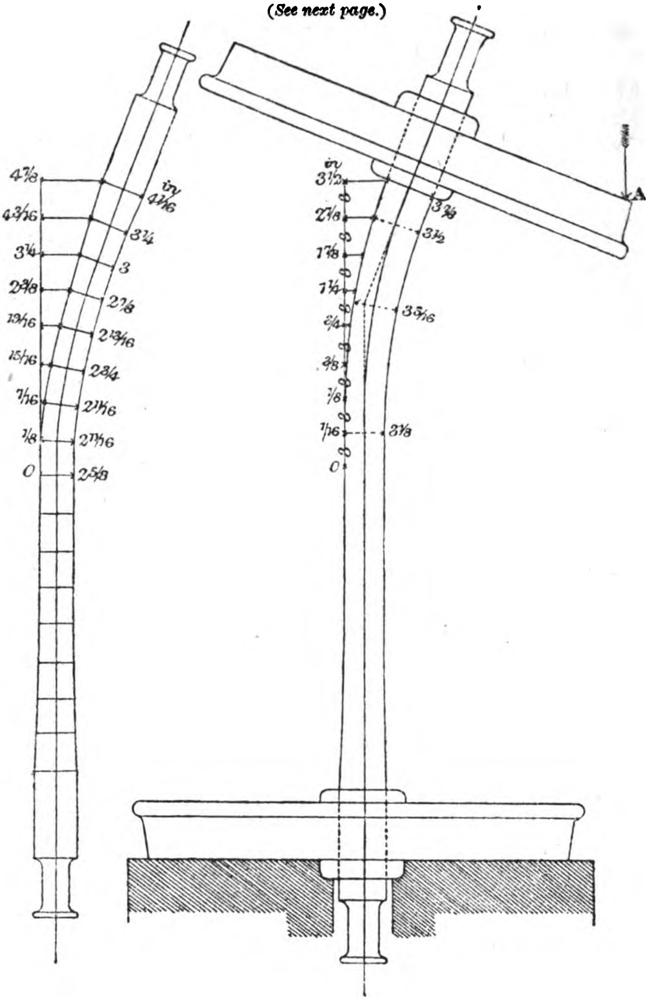
STATEMENT of the WEIGHT, CAPACITY, and DIMENSIONS of WAGONS.

Description.	Area of Floor.	Content.	Weight of Wagon.	Maximum Load.	Maximum Load to Tare of Wagon.	Maximum Load on each Axle.	Size of Journal.	Maximum Load on each square inch of Journal.	Size of Springs.	Weight of Wheels and Axles.
	Sup. feet.	Cubic feet.	Cwts.	Cwts.			Ins. ins.	Cwts.	Ft. ins. ins. ins.	Cwts. (about).
Prussian Stock—										
Covered	170·44	1,189	116·6	151·6	1·3	119·1	8 × 3¼	2·29	..	30
Low sided, open	166·00	150 }	99·0	163·0	1·64	116·0	8 × 3¼	2·23	..	30
High " "	169·46	419 }								
Ballast	158·87	212	..	..	..	..	..	..	..	..
North-Eastern—										
Double chaldron coal	..	198	67·75	120·0	1·78	79·87	8 × 3½	1·42	..	28
Single " "	..	100	34·00	53·0	1·55	34·5	..	..	..	18
Large hopper "	..	270	99·00	160·0	1·62	115·5	8 × 3½	2·06	3 10 × 4 × 5½	28
Coke wagons	100·7	425	120·00	160·0	1·33	126·0	" "	2·25	" " "	"
" "	101·3	..	118·00	160·0	1·35	125·0	" "	2·23	" " "	"
Very high sided, open	102·0	430	101·00	140·0	1·35	106·5	" "	1·90	" " "	"
High sided "	113·7	256	100·00	160·0	1·60	116·0	" "	2·07	" " "	"
Low " "	108·7	163	96·00	160·0	1·66	114·0	" "	2·03	" " "	"
" " "	106·9	107	97·50	140·0	1·44	104·7	" "	1·87	" " "	"
" " "	92·1	176	80·50	160·0	1·98	106·2	" "	1·90	" " "	"
Great Northern—										
High sided, open	103·8	315	95·0	180·0	1·89	123·5	8 × 3¼	2·38	3 6 × 3 × 5½	28
Madras—High sided, open	127·9	..	103·7	126·0	1·11	97·8	9 × 3¼	1·67	..	34
Great Southern of India—										
Covered	106·0	618	110·0	160·0	1·45	118·0	9 × 3¼	2·01	3 0 × 3 × 4½	34
High sided, open	111·7	280	100·0	160·0	1·60	113·0	" "	1·92	" " "	"
Low " "	111·7	140	90·0	160·0	1·77	108·0	" "	1·84	" " "	"
Ballast	100·0	169	92·0	160·0	1·73	109·0	" "	1·86	" " "	"
Salt	106·3	497	105·0	160·0	1·52	115·5	" "	1·97	" " "	"

all progress. There were, however, matters of detail on which the companies might, with advantage, come to some arrangement, such as uniform size of journal and distance between centre and centre of journal, by which any pair of wheels would suit any vehicle.

FIG. 1. FIG. 2.

(*See next page.*)



Scale $\frac{1}{18}$.

1. Axle bent by hydraulic press, applied at the same point of wheel A, as in Fig. 2.
2. Axle bent by one blow from weight of 17 cwt. falling 9½ feet on the edge of wheel at A.

Mr. Cowper wished to bear testimony to the fact that oil axle-boxes had a friction of 2·4 lbs. per ton, and grease axle-boxes a friction of 8 lbs. That was the result of a careful experiment conducted on the South-Western railway, the details of which were in the Proceedings of the Institution.[1] In reference to the proper shape of an axle, he might draw attention to two figures of axles (page 122) turned for the purpose of experiment to certain dimensions, and a pair of wheels which were put on to the axles for the proof, one being flat on a bed plate, and the weight being allowed to fall on the rim of the other wheel representing the blow upon the wheel in passing through a bad crossing. It would be seen that the axle was bent nearly to a uniform curve as far as the centre of its length. That was the result of experiments conducted some years ago on the London and North-Western railway at Wolverton by Mr. McConnell. A number of axles was tried until a uniform curve was obtained, when the axle was bent by a blow or by hydraulic pressure. He had no doubt that the strain brought upon an axle, when a carriage was passing through a bad crossing, was greater than that produced at any time by the weight of the vehicle.

Mr. Browne, in reply, said he should be sorry to set his opinion against that of Mr. Adams on any general question of construction of railway wagons, or of the general conditions of traffic, that gentleman's experience being so much longer and more varied; but on the question of what wagons would be passed by the Great Western Railway Company he ventured to express an opinion, for the unanswerable reason that he had to build wagons which the Great Western Railway Company would pass, and Mr. Adams had not. In South Wales thousands of wagons were running without spring buffers, and with wheels and axles similar to those shown on the diagrams; not wagons of any particular type and according to any particular specification, but ordinary wagons in general traffic. With regard to the glutting of the spokes, to which exception had been taken, he had not shown any spokes glutted. He was aware that in many wagons that was done, and some persons considered it an improvement. Unglutted spokes were not things of the past. The failure of a wheel in any way in the skeleton was a matter of such extreme rarity, that he did not think any improvement in the skeleton was of much importance. He believed that wheels failed in almost all cases, certainly in the majority of instances, through the wearing out

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 406.

or the cutting down of the journals, or through the splitting-up of bosses. Tires of course wore out, but they could be renewed. The skeleton, except in some cases of accident, would last almost for ever. He was disposed to agree with the views of Mr. Adams with regard to the hollow axle, and thought it a pity that some system of that sort had not been tried. He could not see why a tube of 7 or 8 inches in diameter should not make a much lighter and stronger axle than the solid forged axle at present in use. He wished it had been explained more fully how it was proposed to attach the journals to the wheels, as that was a matter of vital importance. He did not challenge Mr. Adams's views as to the springs, but he failed to see any magical efficacy in the deflection which seemed to be thought essentially necessary. The stiffening of the sole-bars was not a new idea, but was frequently carried out in practice. He much doubted the practical advantage of uniting wrought iron with wood, two materials which behaved so differently under flexure. It was difficult to say how far the two acted together, or how far the whole strain was thrown on the one and not on the other. He could not accept the views of Mr. Berkley, that the starting point of the wagon should be, not the maximum weight marked upon it, but the dimensions which controlled the maximum weight. In making that statement, Mr. Berkley had forgotten that it entirely depended upon the specific gravity of the material to be carried. It was quite possible to load a wagon with 10, 15, or 20 tons of plate iron, but if the material was light, whatever the capacity of the wagon, it was impossible to load it up to anything like its full power. He did not see what could be taken except the weight marked on the wagon, which in all cases was assumed to be the greatest weight that it should be allowed to carry. With reference to the comparison between wood and iron frames, no doubt where teak was employed the difference in cost was not great, but he was not aware that teak was used for ordinary wagons in this country. It was expensive, and he believed it was confined exclusively to hot countries, on account of its possessing peculiar properties enabling it to resist the climate. In this country, it would be as reasonable to build wagons of mahogany or of any other expensive wood. The woods most frequently used were English and American oak, or pitch-pine. The tare weight of the American wagons, as shown in the table, was extremely high, but (as pointed out to him by Mr. Herbert Wallis of the Grand Trunk railway of Canada) the wagons for ordinary goods were obliged to be covered on account of the climate, some protection being

absolutely necessary in severe winter weather. The whole of the cover was mere dead weight, and answered no purpose in the carrying; so that it would partly account for the extraordinary difference to which reference had been made by Mr. Douglas Fox. He regretted that the question of oil as against grease had not been more fully debated. If the figures he had given, obtained direct from Mr. Beattie, of the London and South-Western railway, and confirmed by Mr. Cowper, were true, the resistance of friction with oil was only one-third of that with grease, so that a train worked with oil might be three times as long as a train worked with grease, or three times as heavy. It was a matter on which a railway manager only could properly experiment, and it seemed desirable that the point should be settled, especially as Mr. Clayton's figures showed results so different from Mr. Beattie's. He had not contended that the saving from the use of oil axle-boxes would pay for the increased cost, which was not an important matter. The superiority of oil consisted in the decrease of friction in travelling, and the lessened trouble in regard to the heating of the oil axle-boxes. Where the oil axle-box was used it heated gradually, whereas a grease axle-box was apt to become heated in the course of a few miles' run. The heating of the oil axle-box, therefore, was much more likely to be detected before it became serious.

Mr. J. W. BARRY was anxious to say a few words on the subject of Mr. Adams's Paper, as he thought the matters raised by the Author had not been fully discussed. The importance of the subject of the tare or dead weight of railway rolling stock, especially wagons, could hardly be exaggerated. A writer in the "Edinburgh Review"[1] had lately raised the question, whether the mineral traffic of the country was not being carried on by railway companies at a loss, and the present, therefore, was a fitting time to consider the construction of railway rolling stock, with a view to ascertain whether the right course was being pursued in its design. It was obvious that, if the practice of companies who designed their rolling stock with a small tare was right, the practice of the Midland Company was wrong. The profit of goods and mineral traffic, as distinguished from that of passenger traffic, had never been properly investigated, but unquestionably it was a most important subject, and one that would have to be seriously discussed in the future. It was remarkable that the working expenses of railways, in the aggregate, had risen from 48½ per cent. in 1871, to 55½ per

[1] *Vide* vol. cxliii., p. 352.

cent. in 1874, during which time there had been a large development of the mineral traffic. There were so many, and to some extent antagonistic, circumstances to be taken into account, in considering the well-being of a railway, that he thought companies had gone too far in the departmental nature of their government. Thus in most case of working traffic economically, circumstances were involved affecting not only the rolling stock, but also the permanent way and the locomotive power necessary for working goods traffic. But in ordinary practice the carriages and wagons were usually placed under the almost exclusive management of one superintendent; the permanent way under another, the locomotive department under another; so that matters of extreme importance to the railway, considered as a whole, were viewed more or less from the point of view of the head of each department. For instance it was well known that buffers on mineral wagons, spring drawbars, and tight coupling were all advantageous to the permanent way; but the locomotive superintendent often took another view, and preferred loose couplings, so that he might be able to start a train with a smaller amount of initial strain. Again, oil axle-boxes for the rolling stock were undoubtedly useful in diminishing friction, and were therefore to the advantage of the locomotive department, but this was a matter generally adjudicated on by the head of the carriage or wagon department. He suggested that what was wanted was a more general consideration of the subject by a competent superior engineering authority, so that matters which seemed to clash among the different departments might be considered with a view to the general good of the company. No doubt oil axles added slightly to the cost of the wagons, but that cost might be repaid over and over again in the diminution of friction. With regard to Mr. Beattie's experiments, which he had had the opportunity of to some slight extent checking, it was no doubt true that the friction of oil axle-boxes, when the train was in motion, was considerably less than that of grease axle-boxes. On the other hand, it had been found, and he himself had observed the fact, that the friction of starting vehicles with oil axle-boxes was greater than that of starting vehicles with grease axle-boxes; he thought the reason was that oil being liquid was squeezed out, and the two surfaces of the metal were left in close contact; whereas grease, having greater consistency, left a film between the metals on which the two metals could slide. Mr. Beattie's experiments, however, seemed to show that oil axle-boxes could be relied upon to work with a friction when the vehicle was in motion varying from 2 lbs. to 5 lbs. per ton; whereas grease axle-boxes

showed a friction of from 6 lbs. to 9 lbs. per ton. If this were true, the mere question of a few shillings' additional cost at the outset, and the extra expense, if any, of the oil, were matters of comparatively trifling importance. The superintendent of the wagon department of the Midland Company had stated that that company had tried oil, and given it up; and further, that he had tried all sorts of oil. He had himself made some inquiries on the subject, and he found that on the South-Eastern railway the conclusion had been arrived at, after a careful trial, that the proper thing to use was an expensive kind of oil, cheap oils having been found to be of no advantage to the company. An oil costing about 5*s.* per gallon would work the axle-boxes at the rate of a pint and a half per annum; and with such oil the axle-boxes would work for a year without being touched. It was wise, however, to inspect the axle-boxes about once a month, and when inspected they should be replenished with oil, so as to keep the axle-boxes always nearly full. Cheap oils, besides having the disadvantage that they were inferior in lubricating properties, required that the boxes should be much more frequently replenished, and every time the axle-box was filled there was an opportunity for waste. There was one objection to oil axle-boxes which had not been alluded to, namely, that if they became heated, the pads and tapes conveying the oil to the journal were absolutely destroyed, and that when this took place no lubrication was possible without lifting the underframe and body of the vehicle and putting in new pads and new tapes; he had seen an axle-box at work that was available for both grease and oil, so that in the event of such a mishap it could work temporarily with grease, and the vehicle need not be removed from the train. It had been stated by one of the speakers that, if the figures in connection with Mr. Beattie's experiments were true, the total traction of the train would be reduced by one-half or two-thirds. He did not think that was the case. The total traction of a train was not merely measured by the axle friction; there was the friction of the wheels against the rails, the friction of the engine, the resistance of the wind, and many other matters, making a total resistance of from 15 lbs. to 20 lbs. or 25 lbs. per ton; so that the diminution from 5 lbs. to 2 lbs. due to the use of oil axle-boxes would not reduce the total amount in the proportion mentioned. The time he believed had now arrived for a much more careful series of experiments on the traction of trains, and on the different elements of resistance to motion, than had been tried since the admirable experiments undertaken in 1848 on the Great Western railway, when the whole matter was

looked into with great care. A train was then towed by a dynamometer, and the strains exerted were accurately measured. Nothing of the sort had been tried, so far as he knew, of late years; and the interval since 1848 was a long one, during which many changes had taken place. It would be an advantage to the railway world if these matters were investigated scientifically and carefully by persons who would look at the whole question without bias, and with the object of deducing facts and not of supporting opinions.

Mr. FINDLAY had listened to the discussion with great pleasure, and been particularly interested with its technical and engineering character. It had occurred to him that it might not be out of place to say a few words as to the every-day working of one of the great railways of the kingdom. The view expressed by Mr. Browne as to the desirability of the railway companies agreeing upon a uniform type of wagon in regard to wheels, springs, and general appliances, had been indorsed by many railway engineers and managers, and efforts had been made to bring the companies to a general understanding; but up to the present time, although the matter had been discussed at the Clearing House and elsewhere, the companies had failed to come to any arrangement, as to a uniform type of wagon. Something, however, could be said on the other side. Engineers were of an inventive character, always seeking to effect improvements, and probably if a uniform type of wagon had been adopted, the general progress would have been retarded by the stereotyping of a particular kind of wagon. He did not think Mr. Adams himself would wish that the first wagon built by him for private owners upon railways should be the wagon in use to-day. The London and North-Western Railway Company had used oil in their carriages for many years, and were in favour of it as a lubricator, but he did not think it could be used with advantage or economy for wagons, which had to undergo a great deal of knocking about. There was a difficulty in dealing with the wagons of private owners, and there was waste in keeping oil in the axle-boxes. He believed that the practice of railway companies was the best, that of continuing the use of grease in their wagons, especially private wagons, and using oil as far as possible for carriages. If a uniform understanding amongst railway companies with regard to the use of oil, which was rendered necessary by the exchange of stock, could be arranged, he believed it would be found that oil would be decidedly the most economical, if properly used, for the carriage stock; it had been found to be the best lubricator for engines, and all heavy joints that required much lubrication, and must be so for carriages running at high

speeds. The London and North-Western Railway Company had two standard types of wagons—a low-sided wagon, about 11 inches high and 15 feet long, carrying a load of 7 tons, with a tare of 4 tons 5 cwt., and a high-sided wagon, 22 inches high and of the same length, besides other types necessary to meet the incidents of the traffic, such as timber wagons, coal wagons, covered vans, &c. To carry on the enormous business of the company about forty-two thousand wagons were required, besides about an equal number belonging to private traders. After all, the question was what was the paying load that could be conveyed in the wagons in carrying on the immense traffic of the country. In the conveyance of coal no doubt a full load could be carried, but in the conveyance of goods traffic the amount generally fell far short of a full load. Instead of the load being equal to twice the tare of the wagon, it was almost less than half the tare. He had gone carefully into the matter, and had taken out the load of the goods wagons at some of the principal goods stations, including London, Liverpool, Birmingham, Manchester, Burton, and Birkenhead, and he had found that during the short period over which the inquiry extended, the average paying load was little more than 2 tons 10 cwt. That arose not only from the general character of the traffic, but in a great measure from the competition between the companies. In many instances wagons were sent through to the most distant destinations, even to the north of Scotland, with loads of no more than 10 cwt., for the mere purpose of securing speedy transit and so getting custom. With regard to the general question of economy in working railways (which, after all, was simply a question of the paying load to be carried a given distance), one of the points to be considered was the weight of passenger carriages. The London and North-Western Company had introduced sleeping saloons in the Scotch and Irish mail trains, weighing about 1 ton per passenger. The Midland Company also carried, by means of its Pullman cars and drawing-room saloons, an enormous dead weight with a small paying load. He had from time to time inquired carefully into the cost of working the coal traffic. In 1870 the cost of working a full train-load of coal, consisting of thirty-three wagons, from Wigan to London, with a gross load of 380 tons, and a paying load of 230 tons (7½ tons of coal to each wagon, and 4½ tons tare), was 2*s.* 1*d.* per train mile. Calculating the return mileage with the empty wagons, the cost of conveying that description of traffic was 0·21*d.* per ton per mile. He had no doubt that, looking at the various classes of wagons in use, many persons would expect that the load of a coal train would be something more than an average of

7 tons per wagon, even seven or eight years ago; but he had gone carefully into the matter, and he found that the fact was as he had stated. Mr. Webb, their Locomotive Superintendent, had built a coal engine able to take forty or forty-five wagons of 10 tons each, net load; but even with that engine the average load in practice from Wigan to London was only three wagons more than it was five years ago. The gross load of 1875 was 414 tons, and the net load 252 tons, and the expense of working had risen from 2*s.* 1*d.* per train mile in 1870 to 2*s.* 7*d.* in 1875, the average cost per ton per mile being 0·24*d.* He was inclined to think that if a wagon, with a dead weight of about 4 tons, and carrying 10 tons, could be generally adopted, the cost of conveying the mineral traffic would be reduced, as compared with the cost five years ago, but it would take a long time before the use of this class of wagon would become general. He also attached much importance to the reduction of speed from 15 or 18 miles to 12 miles an hour. With regard to the announced intention of the Midland Railway Company to buy all the private wagons on their system, he could only say that there were two sides to that question. He was not sure that Mr. Adams, and other builders of private wagons, would like to see their business transferred altogether to the railway companies. Colliery owners generally knew pretty well what number of wagons they wanted for their own purposes; it might be fairly assumed that they knew their own business better than the railway companies, and it was a fair question to consider whether anything could be gained by such a revolution as had been suggested in the proposal that railway companies should find wagons for private colliery owners. For himself, he could not indorse the policy which appeared to be thought so desirable on the part of the Midland Company. Very little economy was to be gained in working the traffic from the collieries, owing to the great trouble involved in marshalling, sorting, and shunting the wagons, which would be precisely the same under any circumstances. As to the distribution of empty wagons, there would be some saving. The question arose, should railway companies find wagons for every one who had a colliery, ironstone mines, or limeworks and the like, and to what extent would they be responsible if they failed to find them? The wagon distributor of the London and North-Western Company, who lived at Stafford, received about two hundred telegrams per day in reference to the distribution of the wagons throughout the line. What if he had four hundred, some of them from angry traders, stating that their collieries were stopping or their ships waiting? It appeared to him that there

would be little economy from the proposed change, and that it might result in a great disadvantage. The North Staffordshire Company had undertaken to find wagons for private owners, and it was not too much to say that they had altogether failed in carrying out their policy. They had not been able to comply with the wants of the traders, and they had been forced to return to the previous system. It might, however, be said that that was the case of a poor company not being able to do all that was necessary. The only other case (excepting that of the North-Eastern Railway Company, with regard to which there was some peculiarity in reference to shipping at the particular ports where they had chaldron wagons) was that of the Caledonian Company, which, so far as it had gone, had not succeeded. That company had bought up all the private wagons of certain colliery owners in the Bothwell district, and those owners came to Parliament to show the necessity of another railway company, on the ground that the Caledonian Company had failed to serve them as it had undertaken to do, and the new railway was accordingly granted. The experience, therefore, of those two companies was certainly not in favour of the policy proposed to be adopted by the Midland. As to the general policy of making railways pay, he was quite sure that every one heartily desired to see all railways prosperous, not only in the interests of the shareholders, but in the interests of the public. To accomplish that end all unnecessary outlay of capital should be avoided. When a young man, he remembered asking Mr. Stewart, the late Secretary of the Company, if he was not alarmed at the enormous sums that the London and North-Western Railway Company and other companies were spending, and when it would come to an end, and what would be the case in fifty years' time if the capital of the London and North-Western Company or the Midland should be reckoned by hundreds of millions. Mr. Stewart always consoled him by saying that that was the view the men who started the Liverpool and Manchester, and Grand Junction Companies took at the beginning, but his principle was, "Never stop so long as you can get a fair interest, say 5 per cent., upon your money; and be sure that you have a safe investment." The policy of railway companies at the present day should be to incur no liability upon capital except that which would be immediately recuperative. In the next place, the traffic should always be carried on at paying rates. To accomplish that object the dead weight both of passenger and goods trains should be reduced as far as possible, and the paying load increased. He believed that companies were running trains in competition at too high a rate

of speed, and doing many unnecessary things at an extravagant cost, and that by agreement amongst themselves a great reduction might be effected in the number of trains run, so as to increase largely the carrying capacity of the existing lines, and avoid the expenditure in duplicating the present railways. If directors, engineers, and managers would give a little consideration to these questions (the last of which, he believed, was the most important), he had no fear, notwithstanding the article in the "Edinburgh Review," that railways would continue to be what they now were, a real and substantial property.

Mr. J. W. Emmett said he had been a designer and builder of wagons for many years. He had tried all the various timbers that had been considered suitable for wagon-building purposes. He had not built any iron wagons, neither should he ever think of doing so. With regard to axles, it was now admitted by all practical men that to turn a shoulder on the axle and press the boss of the wheel up to it was a mistake; for axles generally broke at that point. He discontinued that mode sixteen years ago, and in order to prevent the wheels being forced on too far, he coned the axles from 5 inches to $5\frac{1}{4}$ inches to the extent of $\frac{3}{4}$ inch into the back of the boss, thus securing the greatest strength at the general point of failure. A few years ago it was considered desirable to remove the cone from the back to the front of the boss, and thus the full strength of $5\frac{1}{4}$ inches was continued, with the exception of $\frac{1}{4}$ inch which was coned down to 5 inches throughout the seat of the wheel. This alteration, however, was not made owing to failures; for he was not aware of a single axle coned in the manner described failing since the plan was introduced. Hollow axles had been tried twenty years ago, and had proved an entire failure. He had taken out scores, if not hundreds, of such axles, believing that they were not safe to run under wagons. He had not found any great trouble from split bosses, the occurrence of such an accident being rare. With reference to axle-boxes, he had formerly been for years in favour of oil, but experience had taught him that oil was not the right thing to use for lubricating wagon axles or wagon journals. The London and North-Western Company had had some 50-ton trollies specially constructed for carrying heavy weights. They were originally fitted with oil axle-boxes, which proved to be a source of great trouble; they were never sent out without a special attendant with a large quantity of oil to keep the journals cool. This practice went on for a considerable time, and he had had some doubts whether it was advisable to supersede oil by grease

axle-boxes, but he ultimately did so, and the result was that there had been no further complaint about hot axles. He had used all kinds of buffer springs, and had long since come to the conclusion that the laminated buffer springs were the best, as they not only tended to prolong the life of a wagon, but prevented damage to goods, besides answering both for buffing and drawing purposes. They had been applied for a long time to all new merchandise wagons built by the London and North-Western Company. He had also used different kinds of bearing springs, with plates varying in thickness from $\frac{1}{4}$ to $\frac{7}{8}$ inch, and he believed that springs of steel $\frac{3}{8}$ inch thick were the best. He had used many kinds of timber for the construction of wagon frames, including American oak, pitch-pine, and elm, but he believed there was nothing so good, strong, and economical as English oak. He had also combined iron and timber, which, to a limited extent, answered well. As to iron wagons, considering they were liable to so much knocking about in shunting and the like, he thought they were not desirable. He knew from experience that the cost of maintenance of an iron wagon was double that of a wooden wagon, and if an iron wagon came into collision nothing could be done but to take it entirely to pieces to straighten the various parts and to put them together again, the cost of which was nearly as much as that of a new wagon. A good deal had been said about the Taff Vale wagon, which was built especially for carrying coal. In the conveyance of coal, however, a full load could always be carried, which was not the case with regard to general merchandise; and to build short wagons for general merchandise would, in his opinion, be a mistake. Different kinds of goods would have to be loaded one upon another, and would therefore be liable to damage in transit. As to axle-guards, his experience was that the crowns should be made of iron $3\frac{1}{2}$ inches by $\frac{3}{4}$ inch, and the wings of iron $2\frac{1}{2}$ inches by $\frac{3}{4}$ inch, as nothing was more troublesome to wagon-builders than the breakage of axle-guards, and it would be unwise, therefore, to reduce their strength. He thought that wagon-builders were not to be blamed for the great amount of dead weight, and that the principal blame should fall upon the locomotive superintendents, who had increased the power and weight of their engines, and had thereby compelled the wagon-builders to follow their example. The question was not so much what weight a wagon would have to carry. It had to be built to bear the strain of and the jerks in starting a heavy train, and to be able to resist the shocks it was subjected to in shunting and in sudden stoppages.

Mr. ALLPORT observed that he had not expected that the general policy of railway companies would be introduced, and he had therefore no figures to enable him to reply directly to the statements which had been made. The Pullman carriages certainly did not weigh 1 ton per passenger, but he was not prepared to state their exact weight. If there was one question more than another connected with the working of railways to which he had devoted his attention, it was that of the ownership of wagons; and he unhesitatingly expressed his opinion, after years of inquiry and experience, that it was the interest of all railway companies to possess the entire rolling stock of their lines. When he was the manager of the North-Eastern Company, then the York, Newcastle, and Berwick line, every coal owner had his own wagons, and many of them had their own engines. One of the first things he did was to put a stop to that system, and since he left, the North-Eastern Company had carried on the practice which he inaugurated, and thus possessed all the vehicles on their line. It was true they had a large number of chaldron wagons, but by reducing the capacity of all the wagons to one standard, the company was now carrying rather more than double the quantity per annum that the Midland was carrying, with rather fewer wagons. The question was too large a one to enter into on that occasion, but he was sure that if Mr. Findlay, or any other railway manager, would look into it thoroughly in all its bearings, he would arrive at the conclusion that it was far better for a company to possess its own wagons than to allow private owners to supply them, and that was quite apart from the question of safety. The number of accidents occurring with the wagons of private owners was much larger than the number of accidents occurring with the wagons of a railway company. The labour of marshalling and shunting empty wagons was extremely great, and no doubt the diagrams exhibited at a former meeting, showing the complicated arrangements for sorting empty wagons, would be remembered. The Midland Company had no less than 20 miles of sidings for this purpose at one of their sorting stations. All that trouble with the empty wagons would be saved if they were the property of the company. He spoke from great experience as a railway manager, having, he believed, had more experience in coal traffic than any other manager in the kingdom, or, perhaps, in the world, and he believed that sooner or later all wagons conveyed over railways would be possessed by the companies themselves. He was entirely at issue with Mr. Findlay on the subject, and regretted that he was not prepared with the facts and figures to prove the statements he had made.

Mr. Longridge said in France, Germany, Italy, and in Russia, oil axle-boxes were used almost exclusively, both for goods and passenger traffic; and he had been assured by the managers that a great saving in money and labour was effected thereby. The amount of attention required by the oil box was nothing in comparison with that required by a grease box; and he could not understand how, in a country like England, grease boxes were so much used for wagon stock. He had seen in Sweden oil boxes that had been used in a ballast pit for three years without the wagons ever having been lifted, nothing being required but the addition, from time to time, of a little oil. In one case an experiment was made in which a first-class carriage ran every day for twelve months, from Edinburgh to Glasgow and back, without the addition of a single drop of oil, the number of miles run being nearly 29,000. The box was filled with oil when the carriage was set to work, and it was not touched during the twelve months; the quantity of oil used was a little under one pint in each box.

Mr. Gregory proposed to make a few remarks upon the question of construction, raised principally in the Paper of Mr. Browne which professed to give a standard design for a good wagon, combining the greatest possible amount of lightness and economy. The wheel shown could hardly be regarded as a standard of the best form; it was the old-fashioned type, having a wrought-iron skeleton, with a cast-iron boss, and the tire was fastened on by rivets. He did not say that this type should be entirely excluded on railways, and condemned as dangerous, but modern experience had shown that if a pattern wheel were to be adopted, modern appliances should be used by which the tire was held on with more certainty, and less risk of accident incurred, than by the system of riveting. The increased facilities for making wheels with wrought-iron bosses at a slight increase of cost would, he thought, lead to the adoption of such wheels where it was desirable to keep down the weight and, at the same time, to have the greatest amount of efficiency. Mr. Browne, he thought, had refuted his own proposition with reference to a perfectly uniform standard, by the statement he had made as to wagons habitually getting out of date. He had himself repeatedly tried to obtain uniformity to the utmost possible extent in the different elements of wagon construction upon one railway only, and had found, in the course of a few years, that improvements, or supposed improvements, prevented the long maintenance of complete uniformity. At the same time he thought that, without doing away with efficiency or preventing reform, it was desirable as far as possible to have one type of wheel

which could be applied to all the carriages and wagons of any one railway indiscriminately. The difficulty that had been found in the introduction of cast iron for wheels in this country was, that the same kind of iron could not be obtained which was largely used in America. The great extremes of temperature in North America tended to a rapid wearing out of wheels, which in England and on the Continent would stand well. The ordinary old-fashioned form of the wrought-iron skeleton, within cast-iron boss, was found to become rapidly useless on the Canadian railways when they were established, and the cast-iron wheel had superseded it. There was this marked advantage, however, in the use of cast-iron wheels in North America, that all the iron used was charcoal iron of a high quality. It had been suggested that if a demand were to arise charcoal blast furnaces would soon spring into being. Unfortunately, however, there was not in this country enough timber for a supply of sufficient duration for that purpose. He did not quite understand the proposition, that if journals could be maintained the life of a pair of wheels would be indefinite, as he believed that the failures of other parts exceeded the failures of the journals themselves. Nor could he admit the proposition that through drawbars were in themselves a defect. He thought that the drawbar might be made an element of strength and part of the actual structure of the wagon. That was the case in many wagons, some designed by himself and some by other persons. He desired to bear his testimony to the extreme importance of having buffing and traction springs applied to vehicles of all descriptions, partly to save the rolling stock itself and partly to save the load carried in the wagons, if it were of a fragile character. At the same time traction and buffing springs for wagons need not be so perfect in their action or be so costly as for carriages, as was shown by the large use of outside buffers in wagons. He believed that any comparisons of the capacity of wagons upon different railways, and of the tare as compared with profitable load, would be fallacious without the consideration of the purposes to which the wagons were applied. While the diminution of the varieties of rolling stock was most important, the various characters of the loads to be carried would sometimes interfere with the limitation of the varieties of design, and would certainly prevent the making of any certain comparisons between the tare and the profitable load. It was also necessary to consider not only the material carried, but the duty which a wagon had to do: whether it had to run long lengths with a full load, or shorter lengths and uncertain distances, sometimes with a full load and sometimes

empty. It had been stated that pitch-pine was, weight for weight, of greater strength than oak. That might be true with regard to American oak, which was extremely different in its strength from English oak. Before it was admitted that English oak was weaker, weight for weight, than pitch-pine, he thought some further information on the subject should be obtained.

Mr. Adams desired to remark, in reference to Mr. Clayton's statement that 20 per cent. of the private wagons would require replacement after ten years, that this was not so. Out of three thousand wagons of the type shown in Fig. 1, Plate 10, supplied by him to the Midland Wagon Company, probably after a life of twenty years the whole were at work and earning rental. Repairs during the first ten years of the life of the wagons had cost about £2 10*s.* per annum per wagon, and his practice was after ten years to thoroughly overhaul the wagon at a cost of about £13, the wagon being then in as good working order as when new. Depreciation written off at the rate of 5 per cent. per annum was found to be more than sufficient. It had also been said that the cost of grease for wagons was about £2 for ten years, or 4*s.* per annum per wagon. His experience—and it was large, for he manufactured his own grease—showed that it cost 8*s.* per annum. He agreed that tires 2½ inches thick were more economical in maintenance than those 1¾ inch thick, but it appeared to be forgotten that the difference of cost, to commence with, was about £2, and of the weight about 300 lbs. per wagon, so that the railway company, for the small economy to the wagon department, were for four years or more hauling 300 lbs. of materials for repairs, to the serious loss of the locomotive and permanent way departments. The experience of the London and North-Western had proved that the load actually carried by freight wagon was far below the capacity of the wagon. That being so, there was greater necessity for reduction in tare of wagons. He was satisfied that by the expenditure of a few hundred pounds in experiments, and by careful thought, without departing much from the beaten track, he could design 8-ton coal and goods wagons with laminated drawing and buffing springs that should tare 3 tons 10 cwt., and be equally as strong in all respects as the present Midland railway wagons taring 4 tons 14 cwt., and as efficient for high speeds, when required, as passenger stock.

Mr. Browne remarked, through the Secretary, that Mr. Gregory had somewhat misunderstood the diagrams exhibited by him. They were not by any means intended to represent a model wagon —the most efficient and economical that could be built—but (as ex-

plained in the Paper) simply the ordinary type of commercial wagon made for private owners at the present day. Thus, as to wheels and axles, he did not regard the design exhibited as the best that could be made, but it was certainly one of the most common now in use. He had mentioned other forms, which he considered would be improvements. With regard to uniformity of design, the place where this was of most importance was in the ironwork of a wagon, and in this there seemed little room for any great changes, except, possibly, in the draw-gear. In point of fact the different parts were now nearly similar on all lines, and what he urged was that they should be made exactly similar, and so interchangeable. For instance, the journals preferred by different companies varied perhaps by ½ inch in the length only, or ⅛ inch in the diameter: but this was quite enough to prevent the same pattern of axle-box serving for both. With regard to the failure of journals, it was clear that in wheels and axles the only parts subject to wear were the tires and the journals, and that under the present system the former could be replaced, but the latter could not. Journals were also specially liable to injury by running hot, or by dirt getting into the boxes; and any plan that would enable them to be renewed would be, therefore, of unquestionable advantage.

Major T. F. Dowden, R.E., observed, through the Secretary, that the subject under discussion might be included in the question, What was the proper load for an ordinary wagon? The subject had been approached from the wagon-builders' point of view—given the load of freight, to design the vehicle. In effect Mr. Browne contended that the dimensions found in the practice of the leading English railways had in general been assumed as substantially correct, and that builders, at the present moment, were guided by the result of that experience. The load of freight recommended was 8 tons, and in the Author's opinion it could be done on his design with a wagon weighing 3 tons 18 cwt., while the weight of those now running on the chief railways was 4 tons 8 cwt. to 5 tons 10 cwt., from which a saving was anticipated in the amount of dead weight hauled for a given amount of freight. Mr. Adams also laid great stress on the reduction of dead weight, which was thought to conduce to economy. But could not this reduction of dead weight be carried too far? It had been mentioned that the Midland, the London and North-Western, and the Great Western railway companies did from time to time actually issue instructions tending to increase the proportion of dead weight. But in drawing deductions from the experience

of the leading English lines, the conditions under which the traffic was carried on must not be lost sight of. It seemed impossible to treat the proportion of dead weight to freight apart from the general question that affected all mechanical working, that a machine for the best effect should be proportioned to the work it had to do, and all the parts should bear the same proportion to one another and the whole. The wagon to convey the goods was merely one small portion of a large machine constituting a railway. It could not be moved without the other appliances of rails, sleepers, sidings, stations, &c. The question then arose, was the object to do a large quantity of work in an abnormally short time, or to do the work as cheaply as possible? If a machine was overworked, or made on too small a scale for a given quantity of work, the result would be an excess of cost per unit of work done, and a decrease of the dividend from that cause. Unless some reasons existed for overworking, such as the existence of a monopoly, a high rate of interest for borrowed capital, or a great demand enabling high rates to be charged, there would be no inducement to overwork machinery. If railways had to be overworked it might be done by limiting the expansion of all the parts of the great machine in the same proportion, and increasing only a few. The experience of the last twenty years had been in this direction. The number, size, and weight of engines and vehicles had been increased, while the paying loads had been increased in a much larger ratio, to enable the extended traffic to be carried on without the expense of doubling the lines, &c. Wagons which started by bearing an equal ratio of weight to the freight had been overloaded from 30 to 50 per cent., and efforts were constantly made to continue the process still further, not only for the accommodation of the old heavy lines, but also for the new ones being projected; and with lamentable results in the way of expense, to say nothing of accidents involving loss of life. It was said that the lives of wagons had been habitually cut short by accidents in twelve years on the average. This really meant the replacement of the stock in twelve years. The valuable tables of renewals of rolling stock contributed to the Institution at various times, showed that this rate of renewal in England was the rule rather than the exception. In India the experience of the great lines, which were, however, not worked up to their full capacity within, say, on the average, 25 per cent., showed that the renewals more nearly accorded with the interest (5 per cent.) on their value. There was evidence that in Bombay at least, the lines would be well maintained for a sum equal to the

market rate of interest on the value of the rolling stock, both in the matter of engines and vehicles. This rate appeared properly to indicate the desirable proportion of repairs and renewals in the interest of the dividends, as far as the working expenses alone were concerned. For if the durability of the rolling stock, with the amount of work the whole line was constructed to accommodate with least expense per unit, was too little, there would either be a loss of power by the withdrawal of wagons for too frequent repair, or there must be an increased capital stock maintained to provide for a continuous service, and the dividends could in no case be a maximum, in as far as working expenses were at a minimum. Not only would increased shop-room be required, but the repairs themselves would be more expensive in such a case. Evidently the best effect was to be got by expending capital in producing wagons up to a limit of durability, which would be reached when the cost of their repair or replacement was equal to the interest on their construction. If more capital than this were spent in producing excessive durability, it would be waste for which there was no demand, and the expense of maintenance from the deterioration of the excess material must be increased. Dividends must consequently suffer in either case.

If it were conceded that the repairs and renewals should equal the rate of interest of money on the cost of construction, it would be impossible to recognise the experience of the heavy lines in England as a standard suitable for all railways, with all its faults including proportion of dead weight to freight, which resulted in a rate of repair and renewal of at least double and sometimes treble the rate of interest on the cost of construction. Such experience was no doubt an excellent guide to the construction of wagons on particular lines similarly situated as regarded monopoly, &c.; and the weights and durability of wagons arrived at in this manner would be the natural outcome of the whole condition of working the entire railway.

As regarded the destructive effect of a rolling load in a given time, including wagon and freight, it seemed evident that it would be in proportion to the whole weight moved at a given velocity. The concentration of a greater weight on a single wheel than was necessary—whether that weight proceeded from freight or weight of wagon—must necessitate a greater weight in every part of the permanent way and wagons than would otherwise be required. The question was not so much how to put the greatest load into a wagon, as how to carry the total traffic, with the entire machinery constituting a complete piece

of railway, at the cheapest rate and in the most efficient manner. With excessive wheel-weights not only was the durability of the rolling stock and permanent way diminished, and an excessive amount of material required in construction, but the expense of maintenance of the way and stock was increased. In every way the dividends must suffer. This state of things could only be sustained by high rates if the railway was to be a financial success. In India the conditions were different. The lowest rates were the only ones that could be effective. There would evidently be the smallest wheel-weights and the greatest amount of freight, with the smallest gross and dead load resulting in greatest durability of the wagon—if durability was to be got by increased weight—when the wagon was loaded to no more or less than the weight of the wagon itself. This proportion admitted of the smallest amount of capital being spent in the way and works, combined with the greatest efficiency and least expense for maintenance.

It might be said that the loaded wagon-weights per wheel did not determine the weight of the permanent way, which must be calculated from the engine wheel-weights. But the overloading of existing railways had led to increased wheel-weights in the engines, and had caused a departure from the ratio of equality which was evidently desirable. This was only one of the evils of which the disproportion of freight to wagon-weight was an outcome, in the endeavour to produce an equality of wheel-weights necessitated by the exaggerated train-loads.

In concluding that the load of a wagon should be equal to the weight of the wagon itself the maximum load was referred to. The wagons must evidently all be calculated to bear the maximum load, though they might not always be employed in conveying it, so that the error of having special classes of wagons for general traffic purposes might not be incurred. A 5-ton wagon might contain from 1 ton to 5 tons of general goods, according to their nature and the circumstances of the consignment, and it had been pointed out how the average loads of fully freighted wagons in France, the only country where accurate information was obtainable on the subject, were actually less than 50 per cent. only of the loads the wagons were calculated to bear, showing how small a portion of the traffic was of a high specific gravity. It had been also shown how a small increment of weight was required in a wagon to accommodate a larger increment of freight, and it could not therefore be disadvantageous to have all the wagons calculated to bear the maximum weights, to avoid inconvenience in the traffic. But the indefinite increase in the capacity of indi-

vidual wagons was practically not called for. No greater mistake could be made than regarding the work of a railway as that of a multitude of separate machines, and thus destroying the uniformity of the parts of the whole railway as an individual machine. Evidence was not wanting in the records of Indian railway practice that all classes of wagons were used for all descriptions of traffic, except specialities like water-tanks, &c., and that the average freight load of all was about the same. If this were the case, any excess of material in wagons, however little, to enable them to take excessive freights must be so much useless dead weight.

It had been contended that the strength of railway vehicles must not, as in other structures, be proportioned to their loads. This seemed to be true to this extent, that the strength related to dynamics rather than statics, but the data as regarded the forces put in operation were not clear, and it must be exceedingly difficult for a wagon-designer to predict the life of his wagon. He was obliged to have recourse to the results of trials of wagons already in work, and at the outset of his inquiry, generally found that there was absolutely no record of the cost and performances of any wagons to go by.

One would think, when the dividends were dependent to such a large extent on the amount of capital spent and the amount of work done at the least cost of repair, that such a mode of registration would be adopted as to show, under what circumstances the greatest effect was to be got out of the smallest capital at the least expense. As a fact, however, such steps were hardly ever taken owing to a want of that concentration of intelligent thought, in the administration of the railway as a whole, which was forthcoming in such an eminent degree in all the various subordinate departments. The engineers, the traffic and locomotive superintendents, and the accountants had, however, each in their own line sufficient employment, but they would often be most grateful for accurate information only to be obtained through the supreme head of the administration, which would enable them to exercise greater economy in the working of their departments. Certainly one of the first things they ought to know was, the amount of mechanical work being done by them to compare with the expenses they were incurring, and weekly statements of the gross ton-mileage performed ought to be published as regularly as the weekly statements of traffic receipts.

It was a fact that the information on the waybills and guards' reports would generally enable the locomotive superintendents to know the work in ton-mileage of every single vehicle on the road. With such information at hand it would not be difficult to find out

what kind of construction was most economical, for there would be the actual test of figures.

It did not seem less desirable to have the records of work done by individual wagons than of individual engines, and it was certain that the expense of attaining the information would be small compared with the economy it might lead to, though it might appear at first sight to be a considerable undertaking. It was not improbable that if the necessity of the register was fully recognised, means would be found for easily registering the ton-mileage on the wagon by an index, to be moved by the loading clerk at the time the waybill was made out; or by the guard of the train in making out his train reports in the case of empties.

If the destructive effort of a rolling load extending over a given period might be measured on a given road, by the weight multiplied by the velocity, the weight of passenger vehicles would generally be heavier than of goods, both being empty to provide against it; but the gross load of fully freighted vehicles of either class would give heavier gross weights of goods than of passenger vehicles.

The higher speed of the passenger trains must necessitate greater strength in the vehicles, only to be got at some addition to the weight with given efficiency of design. The gross wheel-weights must be diminished as the speed increased to preserve equality of effort. On the other hand, the overworking of heavy lines in England necessitated a rate of speed, for goods and minerals, which largely accounted for the short life of the rolling stock and permanent way. Add to this the heavy wagon-loads and light wagon-weights, and there could be no wonder at the favourable rate of renewals in India compared with those in England. It would be a pity to lose sight of this in seeking to apply English experience to Indian lines.

Mr. Walmsley Stanley observed, through the Secretary, that, like all other structures, railway wagons must be constructed for the special requirements of the lines upon which they had to work, and for the nature of the material to be carried; upon this depended not only the dimensions of the wagon, but the subservient parts, and the material of construction. For example, on lines where the principal traffic was mineral, with sharp curves, steep gradients, and slow speed, the wagon and wheel-base must be short and buffers and continuous drawbars dispensed with; but where the same mineral traffic had to be taken in connection with large passenger traffic, or where mixed goods and passenger trains were run at quick speeds, it was indispensable for economy, comfort, and safety to have both buffers and continuous drawbars, &c. So

again with the materials to be carried; for coal, iron ore, and such minerals, a short wagon could be used, but when iron bars, planks, and such like goods were carried, a longer wagon must be adopted; and, in this latter case, and especially when mixed trains were run, it was desirable to construct the underframes of rolled girders, otherwise there was a tendency to swag in the centre or drop at the ends, and the buffer height became uneven. As a rule, he considered that wagons for the generality of traffic could be most economically constructed of timber: such wagons would have less dead load, and would be more elastic and equally durable as those with iron frames. During the past five years he had been employed in constructing and managing railways in Sweden, where the principal railways belonged to the State, and it was the universal custom on them, and on nearly all the private lines, to use iron underframes both for passenger and goods wagons, fitted with buffers, continuous drawbars, and axle-boxes adapted for oil. They were most substantially and well built, but, as would be observed from the following table, were expensive in first cost.

DESCRIPTION of DIFFERENT CLASSES of ROLLING STOCK SUPPLIED to the SWEDISH GOVERNMENT in 1873.

Class of Stock.	Weight of Carriage.	Load carried.	Length over Buffer.	Length of Body.	Breadth of Body.	Height of Body.	Wheel base.	Cost per Carriage.	Number of Seats.
	Tons.	Tons.	Feet.	Feet.	Feet.	Feet.	Feet.	£.	
First class carriage[1]	9⅜	..	29·80	26·77	9·00	7·25	13½	621	18
Second[1] „ .	8⅝	..	29·80	22·66	9·00	7·25	13½	588	21
Third[2] „ .	8 1/12	..	31·00	23·66	9·00	7·00	13½	347	46
Baggage vans[3] .	7⅓	6	23·60	21·00	8·00	7·40	12·00	241	
Covered goods .	5⅝	7½	23·60	21·42	8·00	7·50	12·00	199	
Open low goods .	4¾	8⅓	21·00	18·50	8·00	2·25	12·00	140	
Plank wagons .	4¾	8⅓ [4]	25·80	22·75	8·00	0·87	12·27	139	

[1] Three sofa coupés, through passage, platform entrance at end.
[2] Two coupés of eighteen places, and one of ten places.
[3] Conductor's coupé with overhead look-out 1¼ foot higher.
[4] The most recently constructed wagons carried 10 tons.

The wheels and axles of all rolling stock on these lines were alike, and cost £26 10*s*. per pair, or £43 10*s*. per vehicle. This deducted from the above cost gave the cost of the wagon and carriage bodies.

He had found it more economical for the long timber and iron wagons to use a sole of timber strengthened by angle iron. But

he considered that many of the advantages of this rolling stock were thrown away by working it with couplings so slack that there was a space of 3 or 4 inches between the buffers when in motion. The Swedish wagons had all suspended springs; steel axles and tires, and either wrought or cast boss, and wrought arms to the wheels—the tires being shrunk on to the rim and bolted in the ordinary way; the axle-boxes, for the most part, were made for oil, with a cotton pad below, and had a replenishing chamber covered by a spring flap. These boxes were uneconomical, and any evil-disposed person could withdraw the oil from them. He adopted on the stock constructed by him the Beuther box, with either a screw or a cup with spring cover for replenishing. On account of the climate oil was universally used on all Swedish railways, and the cost between a Beuther box and any of the others there in use was not large; but he thought they might be adopted on all English railways with advantage. True their cost was about £1 10*s.* the set more than an ordinary grease box, but this extra cost would be soon covered by the saving effected in grease, labour, and engine power. A train fitted with such boxes was more easily moved than when fitted with grease-boxes, and any axle insufficiently supplied with oil became so gradually heated that it was easily detected before mischief was done. He had, during construction, ballast wagons at work in a gravel pit for twelve months without being lifted or re-supplied with oil, and at the end of that time the boxes were found half full of clean oil, and the axles in a beautiful state of preservation: the stock had now been working about five years, and it was a rare occurrence to have to lift a wagon for a hot box. The traffic on the lines constructed by him consisted principally of iron ore, bar, and pig iron, the weight of the wagons was about 4¾ tons, and they carried a load of 10 tons. Beuther's axle-boxes were, he believed, now in use on the following railways:—North British, Caledonian, Festiniog, East and West Junction, Belfast and Northern Counties, Swedish Central, Oxelsund Flen and Westmanlands, South Australian, New Zealand, Carnatic, Western Buenos Ayres, Dutch, Rio Tinto, Antifagasta and Salar, Bolivar, Madras, &c. According to a recent trial on the North British a first and second-class composite ran 29,000 miles and was then lifted, consuming

	s.	*d.*
½ gallon rape oil at 3*s.* 10*d.*	1	11
¼ „ petroleum at 1*s.* 10*d.*	0	5½
Total	2	4½

or about 1*d.* per 1,000 miles, and equally good results had been obtained on other lines, but vested interests in the old system had acted prejudicially against adopting any new system, and perhaps the first extra cost had prevented their being universally adopted.

May 16, 1876.

JAMES ABERNETHY, Vice-President,
in the Chair.

The discussion upon the Papers, Nos. 1,476 and 1,472, by Messrs. W. R. Browne and W. A. Adams respectively, occupied the whole of this evening.

May 23, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

No. 1,479.—"On the Permanent Way of Railways." By R. PRICE-WILLIAMS, M. Inst. C.E.

WHEN, ten years since, the subject of the maintenance and renewals of permanent way was discussed at this Institution, steel rails may be said to have been on their trial. In the few instances where they had then been used, they were laid down rather as an experiment at stations, and in situations where, from the slow speed of the traffic, no risk was incurred of those sudden fractures to which it was feared their brittle character rendered them peculiarly liable. Experience, however, has shown that these fears were groundless, and that steel, with the small percentage of carbon used for rails, is a material greatly superior to iron, both in strength and durability, and not more liable to sudden fracture.

At the present time, where the traffic is heavy and concentrated, steel rails have entirely superseded iron rails in the renewals of the permanent way; and already the main lines of the London and North-Western, the Great Northern, and other principal railways have been to a great extent relaid with this material; the recent reduction in the cost of manufacture renders it probable that, ere long, steel will be exclusively used for the manufacture of rails.

The Author showed in 1865 that the average life of iron rails on certain portions of the Great Northern railway only amounted to three years.[1] Such, however, has been the growth of traffic in the meantime on this railway, that the tonnage of goods and minerals has been nearly trebled;[2] while on the North-Eastern, the Midland, and the Manchester, Sheffield and Lincolnshire railways, the increase has been even greater, the tonnage in the case of the latter company having been, in the same period, more than trebled.[3]

Having regard to the fact that, ten years ago, the life of iron rails

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 361.
[2] 177·34 per cent increase. See Table 1, Appendix.
[3] 219·05 per cent. increase. See Table 1, Appendix.

on some of the most heavily worked lines of railway was barely three years, it is questionable whether now, with three times the amount of traffic, it would be possible to carry it on without steel rails.

That this large additional tonnage should have been attended with a proportionate augmentation of the cost of the maintenance and renewals of the permanent way is only what might have been expected, even had there not been a general advance in the price of labour and materials. It is, however, worthy of note that, on all the railways dealt with in this Paper, the cost per mile of maintenance and renewals has not risen in the same proportion; a fact which testifies to the more durable character of the materials employed, and to the consequent saving in the labour of maintenance.

From Table 2 in the Appendix, giving the increase in the cost during the last ten years of the maintenance and renewals on nine of the principal English railways, it will be seen that whereas the Great Northern tonnage has risen 177·34 per cent., the cost per mile of the maintenance and renewals of the permanent way has only increased 49 per cent. Again, on the Midland, while the tonnage has been in a similar period more than doubled,[1] the increase in the cost of maintenance and renewals has only been 64 per cent., the chief portion being due to the substitution latterly of heavier and more durable materials, especially steel rails, the advance in the cost of labour having only amounted to 51 per cent., while in the cost per mile of the materials in the same period it has been 92 per cent. This is still more strikingly shown in the case of the Manchester and Sheffield railway, where, notwithstanding the tonnage has been more than trebled during the last ten years,[2] the total charges under the head of maintenance and renewals of way have only risen 66·68 per cent. Here again the principal part of the increase has been in the cost of materials (73 per cent.), the cost per mile of the labour having, during the last six years, only advanced 34·34 per cent.

The relatively small increase in the cost per mile for labour is also observable in some of the railways south of the Thames; on the South-Eastern, for instance, it has only been 0·15 per cent., as compared with 45·93 per cent. in materials. The increase in the total charges for maintenance and renewals of way on this

[1] 113 per cent. increase. See Table 1, Appendix.
[2] 219 per cent. See Table 1, Appendix.

railway has only amounted to 1·69 per cent. during the last ten years, as compared with 71·49 per cent. in the tonnage.

On the London and Brighton railway, the rise in the cost per mile for wages during the last six years has been only 6·04 per cent., while the cost per mile for materials has increased 77·18 per cent. A considerable advance, however, has occurred in the staff and office charges on some of the lines south of the Thames, amounting, on the London and South-Western, to 53·61 per cent., and on the South-Eastern to 43·14 per cent. per mile; but the London and Brighton shows a decrease of 39·18 per cent. On the lines north of the Thames, also, there has been a decrease under this head on the North-Eastern and the Great Northern railways.

In the latter half of the year 1868, when railway companies were obliged to adopt a uniform system for their half-yearly reports, besides other important alterations, the distinction between the maintenance and renewals of permanent way was abolished; while the cost of the maintenance and renewals of sidings, points and crossings, previously included under the head of station works, now properly forms part of the charges for maintenance and renewals of way.

To compare the cost of the different items included under the head of permanent way, in the new and the old form of half-yearly reports, the Author has, for the years preceding 1868, as far as possible arranged the tables and diagrams in accordance with the altered form of reports.

In order, however, fairly to contrast the cost of maintenance and renewals on different railways, much more is required than the present uniformity in the half-yearly reports. The gradients, weight, and speed of traffic of each railway have to be considered, as also the proportion of double to single miles of line; and further, the relative mileage of sidings, and the mileage of triple and quadruple lines, which varies considerably; for while the cost of their maintenance and renewal is included under this head in the half-yearly reports, no account is taken of the mileage of either the sidings or the relief lines.

On the other hand, according to the usual method of estimating the cost of maintenance and renewals a mile of single line counts for as much as a mile of double line; the assumption being that, as it carries traffic both ways, the amount of wear and tear, and the consequent cost of repair, must necessarily be equal to that on each of the double lines of way.

To afford a common basis for comparison, and at the same time

to enable a reliable estimate to be made of the life values of the permanent way on different railways, the Author has in the tables given the cost of maintenance and renewals, both per mile of railway and per mile of single line.

Table 3, giving the cost of maintenance and renewals per mile of railway, during the last ten years shows, in all cases, much greater variation than the cost per mile of single line; not only does the proportion of single line vary considerably on different railways, but also on the same railway at different periods; for instance, the mileage of single line on the Great Northern railway in 1865 was 22·5 per cent.[1] of the total length maintained, whereas in 1875 it amounted to 21·7 per cent.[2] The charge for maintenance and renewals per mile of single line in the former year was 56½ per cent. of the cost per mile of railway; while in the latter year it was 56 per cent. On the London and Brighton railway the proportion of single line to the total mileage of railway maintained was only 20·9 per cent.[3] in 1865, as compared with 27·7 per cent. in 1875;[4] while the mileage of five, four, and three lines of way, which in the former year amounted altogether to only 29½ miles of single line, had increased in 1875 to 67½ miles; similarly the average charge for maintenance and renewals per mile of single line, which in 1865 was 53 per cent. of the cost per mile of railway, amounted in 1875 to 55 per cent.

"Money Life" of the Permanent Way on the Great Northern.

The cost of relaying a mile of single line on the Great Northern in 1865, when iron rails were used, was £1,371 (credit being allowed for the old materials); while the average cost of the maintenance and renewals of a mile of single line in the same year was £134·98.[5] In this latter amount, however, is included

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	Miles.	
1	341	double lines.
	99	single ,,
	440	railway.

	Miles.	
2	438½	double lines.
	122¼	single ,,
	560¾	railway.

	Miles.	
3	195¾	double line.
	51¾	single ,,
	274½	railway.

	Miles.	
4	251¼	double line.
	96¼	single ,,
	347½	railway.

5 Mean of two half-years, Table 3, Appendix.

the staff and office charges, £10·82 per mile; deducting one-half of these as attributable to station works and works of line, and further deducting £12·36 per mile, on account of the maintenance and renewals of the sidings, points, and crossings,[1] there remains a sum of £117·21 per mile as the annual cost of maintaining and renewing the 769 miles of single line on the Great Northern at that time. Dividing £1,371, the net cost of the renewals of a mile of single line, by this annual cost, gives exactly 11·7 years as the average "money life" of the permanent way on the Great Northern system at that time: in other words, such an annual sum was then being spent as would renew the entire mileage of the railway in little less than twelve years.

In 1875, when steel rails were used at £10 per ton, the net cost of relaying a mile of single line was £1,626·283; the cost of maintenance and renewals, after making the deductions in respect of staff and office charges, sidings, &c., already alluded to, was £181·91 per mile; so that the average "money life," for the whole of the 999¼ miles of single line belonging to this company, was only nine years.

Athough the "money life" of the Great Northern permanent way appears to have diminished during the last ten years, it should be remembered that, up to the present time, scarcely one-half of the main line has been relaid with steel rails, and that the iron rails are exposed to the wear and tear of a largely increased traffic; while on the Loop and the East Lincolnshire lines, where the traffic is comparatively light, the original iron rails laid down in 1848, although for the most part still serviceable, are beginning to fail rapidly, and consequently more labour is required in the maintenance of those lines.

That the rise in the price of labour during the last few years has contributed to diminish the "money life" of the permanent way on the Great Northern, as on other railways, there can be no doubt; but the chief cause is due to the increased amount of labour in maintaining the substructure and upholding the surface of the road, through the too yielding nature of the ballast, which, while it constitutes the longest lived portion of the permanent way, is at the same time unquestionably the weakest and most expensive.

By reference to Plate 15, showing the cost of the maintenance, and of the maintenance and renewals of sidings, &c., separately from that of the renewals of way, it will be seen that the

[1] *Vide* Plate 15.

labour in maintenance amounts to four times the labour required in the renewals.

For the purposes of comparison, the cost of the maintenance and renewals of the permanent way of nine of the principal English railways is given, in a condensed form, in Table 3 in the Appendix. The average cost per mile during the last ten years has been highest on the Lancashire and Yorkshire railway, and the "money life" of its permanent way is consequently the shortest, viz., 6·78 years; whilst the maximum "money life," 10·68 and 10·61 years, and the least cost per mile, is on the South-Eastern and the London and Brighton railways. The average annual cost per mile of single line, during the last ten years on the nine railways, has been £157·52; dividing £1,395·67, the net cost of the renewals of a mile of single line with iron rails, and taken at their average price (viz. £7 10*s.*), by this annual cost, it will be found that the mean "money life" of the permanent way of all these railways has only been 8·86 years.

The total expenditure during 1875, in maintaining and renewing the permanent way of these nine railways, with their 6,622 miles of railway or 11,705½ miles of single line, was £2,500,701,[1] or an average of £213·64 per mile of single line. Assuming that steel rails were used for the renewals, which obviously could not have been the case, and that the cost of renewing a mile of single line with steel rails at present prices is £1,626·283 per mile, it follows that the present "money life" of nearly one-half the railway mileage in the kingdom does not amount to more than 7¾ years, and that such a sum must be expended in that short period as would suffice to renew the whole of the permanent way of these railways with steel rails. Since the annual cost of the maintenance and renewals of the permanent way represents $2\frac{1}{10}$ per cent.[1] interest on the ordinary capital of these railway companies, and one year's increased "money life" of the permanent way is equivalent to an addition of ¼ per cent. interest upon this capital, the importance of the efforts now made to render the permanent way more durable, and less expensive to maintain, will not fail to be recognised.

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[1] See Table 4 in the Appendix.

[2] The ordinary capital of the nine railway companies in 1875 was £119,558,959. The amount expended in maintenance and renewals in 1875 was £2,500,701. See Table 4 in the Appendix.

Life of Iron Rails.

The average actual life of the permanent way, or of the materials which constitute it, should not be confounded with what is termed the "money life," the latter being merely a co-efficient to determine the annual cost per mile of the maintenance and renewals in terms of the net cost of the construction.

In the Author's previous Paper, attention was drawn to the short life of iron rails on the descending gradient of 1 in 200 on the Great Northern railway between Potters Bar and Hornsey, where iron rails laid in 1860 were worn out in two and a half years. The rails which replaced them in 1863 apparently show better results, inasmuch as they were not taken out until 1870, after enduring the largely increased traffic of the seven subsequent years. In reality, however, this was not the case; for although the rails were guaranteed to last the full term of seven years, the greater portion had to be renewed, at the cost of the manufacturers, long before the guarantee had expired; 28 per cent. only of the rails remained serviceable at the end of the seventh year, so that the average life was only 5·43 years. The same remark applies to the other guaranteed iron rails which still remain on different portions of the main line (Plate 20). It should be mentioned, that the traffic which passed over the portion of the line between Potters Bar and Hornsey, in the period corresponding to this five and a half years' average life, amounted to 34,000,000 tons.

Wherever iron rails still continue in the main line of the Great Northern, they are either on ascending gradients, or just at the departure end of stations, where the speed of the traffic is least.

How entirely the life of the rails is a question of the tonnage, and of the speed and frequency of the trains, may be judged from the fact just mentioned, and from a reference to the renewal diagrams of the Loop and the East Lincolnshire sections of the Great Northern railway (Plate 17), where, owing to the relatively small traffic and easier gradients, the renewals of the permanent way have been slight.

The Loop line, from Walton Junction to Boston, Lincoln, and Gainsborough, was opened for traffic in 1848; the gradients are better, but the amount of traffic is relatively much smaller than on the main line. The earliest renewal of the up line of any serious extent occurred in 1868, or just twenty years subsequent to the opening of the railway; and it has only been within the

last year or two since the up line was entirely renewed throughout, partly, it will be observed, with steel rails. On a considerable portion of the down line, however, the original rails, after twenty-eight years' wear, are still in a serviceable condition.

The traffic which passed over these rails from the opening of the line to the end of 1875, has been as follows:—

	Trains.	Tons.
Up line	136,760	39,703,560
Down line	134,186	38,550,980

The East Lincolnshire section of the Great Northern railway extends from Boston to Grimsby. It was opened in 1848, the same year as the Loop; its gradients, however, are not so good, but, on the other hand, the traffic is lighter. The renewals on the up line have amounted to 10 miles, or 21 per cent. of the total up mileage, while the renewals on the down line have only been 2 miles, or about 4 per cent. of the total mileage on the down line. The rails, evidently of a superior make, are for the most part fairly and evenly worn, and have still a considerable amount of wear in them. The traffic over the rails on this line since they were first laid has been estimated as follows:—

	Trains.	Tons.
Up line	67,800	13,400,000
Down line	69,800	14,300,000

The accompanying statement (see next page) of the renewals on the Great Northern railway, in each year during the last ten years, shows that a length of 654½ miles, or 85·1 per cent. of the mileage maintained in 1865, has been entirely renewed in that period, and that the average life of the road is 15·54 years.

The decrease in the average life of the permanent way on the Great Northern, is chiefly attributable, as has been already shown, to the short life of iron rails on certain portions of the main line under the greatly augmented traffic of later years, as well as to the recent more rapid failure of the original iron rails on the Loop and the East Lincolnshire lines.

In 1865 the average life of a mile of single line, as deduced from the system of the Great Northern, was sixteen years. The estimated annual cost of the maintenance and renewal of a mile of single line, where the average life of the rails is sixteen years, and when the average life of sleepers, as on the Great Northern, is

eight years, is £128·90, the actual average cost per mile of single line in that year being £134·98.[1]

GREAT NORTHERN RAILWAY. MILEAGE MAINTAINED and MILEAGE RENEWED between the Years 1865 and 1875.

Year.	Miles of Railway maintained. (June half.)	Equivalent Miles of Single Line. (June half.)	Miles of Single Line renewed.	Average Life, Years.
1865	434	769	48	16·02
1866	458	819	50¼	16·50
1867	442	801	56¾	14·12
1868	489	890	73¾	12·07
1869	507	926	62½	14·82
1870	511	930	44½	20·90
1871	511	930	53½	17·38
1872	531½	954½	62¾	15·21
1873	551¼	976½	62¾	15·56
1874	557¾	987½	68½	14·41
1875	558¾	995¼	71¼	13·97
			654½	170·96
				15·54 average.

$$\frac{654 \cdot 5 \times 100}{769} = 85 \cdot 1 \text{ per cent.}$$

THE LIFE OF STEEL RAILS.

The first steel rails ever used on a railway were, it is believed, those laid on the London and North-Western in 1862 at Camden Town, and those laid early in the following year in the arrival and departure platform sidings at Crewe station. Rubbings of the latter have been recently taken by Mr. Webb, M. Inst. C.E., who has furnished the Author with drawings, showing the amount of wear, together with the tonnage which has passed over them, from which Plate 18 has been prepared. The wear of some of these rails has varied considerably; the C and D rails, for instance, have been exposed to exactly the same amount of traffic, still while the wear of the tables of the C rails has been 0·875 inch, equivalent to $\frac{1}{16}$ inch for every 5,142,856 tons, that of the D rails has only been 0·531 inch, or per $\frac{1}{16}$ inch wear, 8,474,576 tons. On an average, the Crewe rails required 9,370,777 tons to wear down the heads to the extent of $\frac{1}{16}$ inch. (See next page.)

[1] Table 3, Appendix.

TABULAR RESULTS showing the WEAR of STEEL RAILS.
Crewe Works, September 30, 1875 (see Table 5, Appendix).

Section.	Original Weight per Yard.	Period in Work.	Estimated Tonnage.	Wear of Tables.	Wear of Tables per Million Tons.	Number of Tons per 1-16th Wear of Tables.
	lbs.	Years.	Tons.	Inch.	Inch.	Tons.
A	75	12	120,000,000	0·625	0·005208	12,000,000
B	"	"	120,000,000	0·625	0·005208	12,000,000
C	"	"	72,000,000	0·875	0·012150	5,142,856
D	"	"	72,000,000	0·531	0·007375	8,474,576
E	"	"	60,000,000	0·406	0·006766	9,236,455
			Average . . .		0·007341	9,370,777

LIFE OF STEEL RAILS ON THE GREAT NORTHERN RAILWAY.

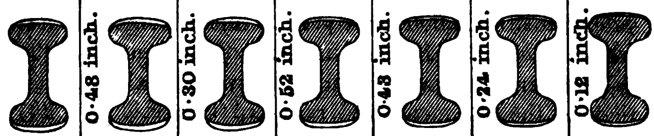
On the Great Northern railway steel rails were first laid in August 1863, at the coal sidings at the King's Cross goods station, where the traffic is particularly heavy. It has been impossible, however, to ascertain the amount of tonnage which has passed over them.

In February 1867 some steel rails were laid in the up and down main lines in Maiden Lane tunnel, at a short distance from the King's Cross passenger station. The traffic over the down-line rails consists almost exclusively of the shunting and marshalling of the trains after their arrival at King's Cross. Although the speed is slow, the traffic is of so incessant a character that the wear of these rails has been more rapid here than on any other part of the line.

With the assistance of Mr. Cockshott, the Superintendent of the line, the Author has been enabled to ascertain the number of engines and vehicles which passed over the rails, and also the amount of traffic over the rails in the adjoining or Copenhagen tunnel, from the time they were first laid to the end of 1875. The worn outline of these rails, the particulars of the tonnage, and the chemical constituents of the steel, are shown on Plate 18, and in Tables 6, 7, and 8, in the Appendix. Here again, as in the Crewe rails, the wear in different rails varies considerably, notwithstanding they have been subjected in several instances to exactly the same amount of traffic. In the case of rail No. 17, Table 6, and Plate 18, for instance, the total wear of the top and bottom tables during a period of nearly nine years has amounted to 0·48 inch under a traffic of 40,329,000 tons (live and dead

weight), equivalent to 5,251,000 tons per $\frac{1}{16}$ inch, whereas the wear of the table of rail No. 18, which immediately adjoins it, has only amounted to 0·30 inch, equivalent to 8,402,000 tons per $\frac{1}{16}$ inch. With the view, therefore, of ascertaining, if possible, the cause of this difference in wear, the Author, with the sanction of Mr. R. Johnson, M. Inst. C.E., has obtained from Mr. Riley, analytical chemist, a careful analysis of the material.

Summary of Table showing the Amount of Wear and Tonnage over Steel Rails in and near Maiden Lane and Copenhagen Tunnels, together with a Chemical Analysis of the Rails (See Table 6 in the Appendix, and Plate 18).



	No. 9.	No. 17.	No. 18.	No. 21.	No. 22.	No. 23.	No. 24.
	Copenhagen Tunnel. (Down.)	Maiden Lane Tunnel. (Up.)	Maiden Lane Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)	North of Copenhagen Tunnel. (Up.)
Total Amount of Wear of both Heads.	0·40 inch.	0·48 inch.	0·30 inch.	0·52 inch.	0·43 inch.	0·24 inch.	0·12 inch.
Tonnage.	96,824,000	40,329,000	40,329,000	63,868,000	63,868,000	59,638,000	59,638,000
Do. per 1-16th Wear.	15,129,000	5,251,000	8,402,000	7,676,000	9,283,000	15,531,000	31,061,000
Chemical Analysis by Mr. Riley.							
Carbon	0·336	0·331	0·296	0·302	*0·538	0·340	†0·270
Silicium	0·034	0·029	0·029	0·034	0·040	*0·062	†0·020
Sulphur	†0·038	0·090	0·051	*0·096	0·059	0·055	0·051
Phosphorus	0·125	0·186	0·144	0·162	0·111	*0·242	†0·100
Iron	99·408	99·451	99·637	99·632	99·249	99·223	99·475
Manganese	0·338	0·353	†0·245	†0·245	0·461	*0·475	0·259
Copper	*0·032	0·020	0·020	†0·018	0·022	0·028	0·025
	100·311	100·460	100·422	100·489	100·480	100·425	100·200

* Maximum percentage. † Minimum percentage.

The results of Mr. Riley's analysis confirm the statement made by Mr. Smith, in his Paper on Bessemer Steel Rails, viz., "that greater hardness of the material did not conduce to the longevity of steel rails."[1] Thus, in rail No. 17, which shows a large extent of wear, the amount of carbon (0·331) is in excess of that in rail No. 18 (0·296), while the wear of No. 18, viz., 0·30 inch, is less, as has already been shown. In both these rails the silicium appears to be exactly the same. The percentage, however, of sulphur, phosphorus, and manganese is considerably higher in the most worn rail. Rail No. 22, situated on the up line at the north end of the Copenhagen tunnel, has, however, by far the largest proportion of carbon, viz., 0·538 per cent. In this instance the wear has been 0·43 inch under a traffic of 63,868,000 tons (live and dead weight), equivalent to 9,283,000 tons per $\frac{1}{16}$ inch. Immediately adjoining, and subject to nearly the same traffic, is rail No. 24, which, although it has the smallest amount of carbon, viz., 0·270 per cent., shows, at the same time, the least wear, equivalent to 31,061,000 tons per $\frac{1}{16}$ inch. Again, in rail No. 23, which adjoins rail No. 24, the proportion of carbon, 0·340 per cent., is considerably greater, while the wear is almost exactly double that in the last-mentioned rail. In this rail (No. 23) there is a large proportion of phosphorus, manganese, and silicium, and the excess of the latter may possibly account for the increased wear.

The sections showing the extent of wear of the steel rails on other portions of the main line, together with particulars of the tonnage and the results of Mr. Riley's analysis, are given in Plate 18, and Tables 7 and 8, Appendix.

Steel rails were first laid in the running road of the Great Northern in 1866 and 1867, on the up line between the Copenhagen tunnel and Hornsey. Since that time considerable portions of the main line have been renewed with this material. Plate 18, No. 10, represents a section of one of the steel rails laid, in November 1867, at the foot of a gradient of 1 in 200 on the up line near Hornsey, the position of which is marked by a × on the section of the line (Plate 17). This rail has been worn to the extent of only 0·15 inch during nine years and a quarter, and the traffic over it in that time has amounted to 294,359 trains, and 66,546,000 tons (live and dead weight), equivalent to a wear of 27,727,000 tons for every $\frac{1}{16}$ inch, the proportion of carbon being 0·320 per cent. (see Table 7, Appendix).

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 72.

Life of Steel Rails on the Metropolitan Railway.

The Metropolitan railway, between Farringdon Street and Bishop's Road, was opened for traffic in January 1863, and the extension to Moorgate Street in December 1865. The line was originally laid throughout with iron rails, which had, in the course of a short time, to be entirely relaid either with steel-top rails or with steel rails. Most of the rails between Moorgate Street and Bishop's Road have already been worn out (Plate 17) and, in some cases, twice renewed after being subject to a little more than ten years of the enormous and incessant traffic on this railway. Between Farringdon Street and Bishop's Road the renewals have occurred chiefly at or near the different stations. This is attributable, no doubt, to the action of the breaks; moreover, the greatest amount of wear is not where the breaks are first applied, but at a point where they may be supposed to have the maximum effect, intermediate between the place where the breaks are first applied and the station platform. This is particularly noticeable in the renewals of the down road at and near the Edgeware Road station.

With regard to the second renewals between Moorgate Street and Farringdon Street, it should be explained, that these were not necessitated by the rails being worn out, but in order to secure a reserve for repairs on other parts of the line where flange rails are still in use, the double-headed section of rail having recently been substituted for the flange rail by the Metropolitan Company.

Sections of worn rails in the Clerkenwell tunnel are shown on Plate 18. The difference between the wear exhibited by the two sections is attributable, in some measure, to the fact that the one which was most worn was in a wet place, whereas the other rail was in a dry part of the tunnel.

Hammering and Cogging Ingots.

In Mr. Hackney's Paper on Steel,[1] the process of hammering the ingot is recommended in preference to first 'cogging' it, and then rolling it direct into the finished rail; his objection to 'cogging' being, "that the tearing action of the rolls injures the metal in its unwrought state, making it loose in texture, and often causing cracks in the surface, while the direct blows of a hammer consolidate and toughen it, and do not tend to crack it." With a view

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 42.

of practically testing the relative merits of cogging and hammering, the Author, with the co-operation of Mr Samuel Fox, of the Stocksbridge Works, and of Mr. George Wilson, of the Cyclops Works, at Sheffield, had some rails, made from hammered and cogged ingots respectively, tested at Mr. Kirkaldy's works. Both the hammered and the cogged ingots were obtained from the same Bessemer 'blow.' The results (Plate 19) show conclusively that, so far as strength is concerned, the rail rolled direct from the cogged ingot has decidedly the advantage. The average "ultimate stress" of the rails, on 5-feet bearings, made out of the hammered ingot, was 84,492 lbs., whereas that of the cogged rails was 86,482 lbs., showing 2½ per cent. in favour of the latter. As regards wearing qualities, the steel rails, made from cogged ingots, which were laid on the Great Northern railway in 1866, might be referred to; these rails, after ten years' endurance of the heaviest traffic on that railway, being still in a serviceable condition.

The Author thinks it due to Mr. Fox to state, that from the first he objected to the process of hammering, as being prejudicial, and that he has throughout consistently declined to manufacture rails from hammered ingots.

Fish Plates.

Recent experiments by the Author at Mr. Kirkaldy's, show the relative strength of the fished ends of the rail as compared with that of the solid part of the rail (Plate 19). The average ultimate stress of four pieces of solid rail, placed between bearings 5 feet apart, was 73,345 lbs.; while in the case of the deep fish plates of the form shown in section in Plate 19, the "ultimate stress" varied from 48,932 lbs., to 47,764 lbs., representing about 66 per cent. of the strength of the solid rail, whereas the average breaking weight of the ordinary fish plates was only 22 per cent. In one instance failure of a deep fish plate took place through the fracture of one of the bolts. In another through the breaking of the web of both rails through the bolt-holes, as well as through the fracture of one of the fish plates.

Drilling and Punching Steel Rails.

The weakening effect attributable to punching steel rails has of late been frequently alluded to. With a view of practically ascertaining the loss of strength due to this cause, the Author has carried out a series of experiments at Mr. Kirkaldy's, the results

of which are given in Plates 19 and 20. These refer to the transverse strength with 5-feet bearings of—

1. Pieces of 24-feet steel rails in their ordinary state.
2. Pieces of the same rails with four holes punched at the middle of the rails, at the usual distances apart, for the fish plates.
3. Pieces of the same rail with four holes punched to within $\frac{1}{8}$ inch of the full size of the bolt-hole, the remaining $\frac{1}{8}$ inch being drilled out.
4. Pieces of the same rails with four holes drilled to the full size.
5. Pieces of a 24-feet rail which, after being heated to a red heat and plunged in water, were drilled, partly drilled and punched, and punched.

Summary of Mr. Kirkaldy's Reports C and D (*vide* Plate 19).

Rails heated, and afterwards plunged in water.

—	Stress.				Deflection.				Remarks.
	Elastic.	Relative Strength.	Ultimate.	Relative Strength.	At 30,000 lbs.	Relative Deflection.	Ultimate.	Relative Deflection.	
Rails without holes.	lbs.	Per cent.	lbs.	Per cent.	Inches.	Per cent.	Inches.	Per cent.	
G (cogged)	29,800	..	53,940	..	0·22	..	4·41	..	Snapped.
E do.	27,600	..	49,740	..	0·32	..	4·44	..	Do.
F (hammered)	26,500	..	46,055	..	0·42	..	10·00	..	Unbroken.
H do.	25,700	..	41,745	..	0·76	..	10·00	..	Do.
Mean	27,400	100·0	47,870	100·0	0·43	100·0	7·21	100·0	
Rails with drilled holes.									
H (hammered)	29,300	..	51,705	..	0·61	..	7·24	..	Snapped.
G (cogged)	25,800	..	45,295	..	0·93	..	10·00	..	Unbroken.
E do.	24,500	..	42,725	..	0·97	..	8·30	..	Snapped.
F (hammered)	24,400	..	42,680	..	1·10	..	10·00	..	Unbroken.
Mean	26,500	94·89	45,601	95·26	0·90	209·30	8·88	123·16	
Rails with punched and drilled holes.									
G (cogged)	28,500	..	49,385	..	0·68	..	8·47	..	Snapped.
H (hammered)	27,900	..	46,420	..	0·72	..	10·00	..	Unbroken.
F do.	27,200	..	43,795	..	0·75	..	10·00	..	Do.
E (cogged)	25,800	..	41,520	..	1·28	..	9·58	..	Snapped.
Mean	27,350	99·82	45,280	94·59	0·86	200·00	9·51	131·90	
Rails with punched holes.									
H (hammered)	29,600	..	48,435	..	0·57	..	6·97	..	Snapped.
G (cogged)	26,500	..	45,340	..	0·81	..	6·84	..	Do.
E do.	29,000	..	39,835	..	0·60	..	1·36	..	Do.
F (hammered)	24,700	..	27,570	..	..	..	0 75	..	Do.
Mean	27,450	100·18	40,295	84·18	0·66	153·49	3·98	55·20	

SUMMARY of Mr. KIRKALDY'S REPORTS C and D (*vide* Plate 19)—*continued.*

Rails in ordinary condition.

—	Stress.				Deflection.				Remarks.
	Elastic.	Relative Strength.	Ultimate.	Relative Strength.	At 30,000 lbs.	Relative Deflection.	Ultimate.	Relative Deflection.	
Rails without holes.	lbs.	Per cent.	lbs.	Per cent.	Inches.	Per cent.	Inches.	Per cent.	
D (hammered)	25,800	..	39,490	..	1·24	..	10·0	..	Unbroken.
B do.	25,100	..	39,410	..	1·32	..	10·0	..	Do.
C (cogged)	24,600	..	38,425	..	1·42	..	10·0	..	Do.
A do.	24,200	..	37,385	..	1·50	..	10·0	..	Do.
Mean . . .	24,925	100·0	38,677	100·0	1·37	100·0	10·0	100·0	
Rails with drilled holes.									
D (hammered)	24,200	..	38,940	..	1·40	..	10·0	..	Unbroken.
B do.	24,000	..	38,840	..	1·42	..	10·0	..	Do.
C (cogged)	23,300	..	38,245	..	1·50	..	10·0	..	Do.
A do.	22,800	..	36,645	..	2·06	..	10·0	..	Do.
Mean . . .	23,575	94·58	38,167	98·68	1·59	116·06	10·0	100·0	
Rails with punched and drilled holes.									
C (cogged)	23,700	..	38,620	..	1·61	..	10·0	..	Unbroken.
B (hammered)	22,200	..	38,095	..	1·65	..	9·72	..	Snapped.
D do.	22,500	..	37,698	..	1·69	..	10·0	..	Unbroken.
A (cogged)	23,800	..	36,890	..	1·75	..	10·0	..	Do.
Mean . . .	23,050	92·48	37,826	97·80	1·67	121·90	9·93	99·30	
Rails with punched holes.									
C (cogged)	22,700	..	26,060	..	..	..	0·61	..	Snapped.
D (hammered)	21,600	..	25,665	..	..	..	0·56	..	Do.
B do.	21,800	..	25,205	..	..	..	0·52	..	Do.
A (cogged)	21,900	..	24,230	..	..	..	0·47	..	Do.
Mean . . .	22,000	88·27	25,290	65·39	..	..	0·54	5·60	

SUMMARY of RESULTS on PREVIOUS PAGES.

—	Stress.				Deflection.			
	Elastic.	Relative Strength.	Ultimate.	Relative Strength.	At 30,000 lbs.	Relative Deflection.	Ultimate.	Relative Deflection.
	lbs.	Per cent.	lbs.	Per cent.	Inches.	Per cent.	Inches.	Per cent.
Rails heated and cooled in water (without holes) . . .	27,400	109·93	47,870	123·77	0·43	100·00	7·21	100·00
Do. in ordinary condition do. . . .	24,925	100·00	38,677	100·00	1·37	318·60	10·00	138·69
Rails heated and cooled in water (with drilled holes) . .	26,500	110·29	45,601	119·48	0·90	100·00	8·88	100·00
Do. in ordinary condition do. . .	23,575	100·00	38,167	100·00	1·59	176·67	10·00	112·61
Rails heated and cooled in water (with drilled and punched holes)	27,350	118·66	45,280	119·71	0·86	100·00	9·51	100·00
Do. in ordinary condition do. . .	23,050	100·00	37,826	100·00	1·67	194·19	9·93	104·42
Rails heated and cooled in water (with punched holes) .	27,450	124·77	40,295	159·33	0·66	..	3·98	710·71
Do. in ordinary condition do. .	22,000	100·00	25,290	100·00	..	..	0·56	100·00

That drilled, and partly drilled and punched steel rails, are stronger than punched rails, the summary of Reports C and D clearly shows, the ultimate stress of the steel rails punched cold in the ordinary way being 65·39 per cent. of the ultimate stress of the unpunched rails; whereas the ultimate stress of the drilled rails shows 98·68 per cent., and the partly drilled and punched rails 97·80 per cent., of the stress borne by the unpunched rails.

The Author would direct attention to the remarkable results obtained by plunging the rails while hot into water previous to their being drilled or punched. Both the elastic and the ultimate stress of the drilled, the partly drilled and punched, and particularly the punched rails, is increased by being subjected to this toughening process. Thus the ultimate stress of the punched rails is thereby raised to 40,295 lbs., as compared with 25,290 lbs. borne by the rails punched cold in the ordinary way, showing a clear gain of 59·33 per cent. in favour of the toughened rail. But although the ultimate stress borne by the punched rails is much greater after they have undergone this treatment, the advantage gained by it in the case of drilled and the partly drilled and punched rails is relatively much smaller, the ultimate stress of the toughened drilled rails being only 95 per cent. of the stress borne by the toughened undrilled rails; whereas the ultimate stress of the ordinary drilled rails is 98 per cent. of the ordinary undrilled rail. It should further be observed that the amount of deflection and set is much greater in the untoughened steel rails, except when the rails are punched, in which case the untoughened rails show less deflection.

Conclusion.

In conclusion, the Author would remark that, although the average wear of steel rails proves them to be superior in durability to iron rails, still it must be admitted that the amount of wear in several instances is much greater than it ought to be with the present knowledge of steel manufacture. It is not, therefore, too much to expect that manufacturers will for the future produce steel rails of such uniform quality, as will at least realise the average maximum endurance already met with in some of the steel rails on the Great Northern railway, viz., 30,000,000 tons per $\frac{1}{16}$ inch wear.

With such a quality of steel, and with a larger quantity of the material placed in the head of the rail, as in the case of the "bull-headed" section, which has, to a great extent, superseded the

reversible double-headed rail, a depth of at least $\frac{5}{8}$ inch of the rail-head would be available for wearing purposes. This would give 300,000,000 tons as the average life of a steel rail, as compared with 17,500,000 tons, the ordinary life of iron rails, according to the Great Northern and the Lancashire and Yorkshire experience.[1]

In order fully to realise the effect of such an increase in the enduring quality of steel rails, it may be mentioned that the traffic which during last year passed over the most heavily-worked portion of the Great Northern railway, amounted altogether to 7,110,532 tons, live and dead weight (Table 17, Appendix); consequently the life of steel rails on that portion of the line would be forty-two years, supposing the traffic to remain constant; and the annual cost of the renewals, at present prices, with an average life of forty-two years for the rails and of eight years for the sleepers, would then only amount to £106·60 per mile of single line per annum,[2] instead of £210·09 per mile as at present.[3]

It only remains for the Author to express his obligations to Mr. R. Johnson, for allowing him to exhibit the sectional diagram of the renewals on the Great Northern from the opening of the line up to the present time, together with the diagrams showing the rubbings of the worn steel rails; and for other information relative to the permanent way of the Great Northern railway, which has been largely taken advantage of. His thanks are also due to Mr. Tomlinson, M. Inst. C.E., for the diagram showing the renewals of steel rails on the Metropolitan railway, and for other valuable information. He has at the same time to express his indebtedness to the chief officers of the other railway companies, who kindly furnished information in regard to the cost of maintenance of the permanent way of the railways under their charge.

The communication is accompanied by a series of diagrams, from which Plates 12 to 20 have been compiled.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 362.
[2] Table 15, Appendix. [3] Table 3, Appendix.

LIST OF DIAGRAMS.

[APPENDIX.

APPENDIX.

TABLE 1.—INCREASE PER CENT. of MILES MAINTAINED, GROSS RECEIPTS and TONNAGE, BETWEEN DEC. 31, 1864, and DEC. 31, 1874.

Name of Company.	Year ending Dec. 31.	Miles maintained.	Increase per cent.		Gross Receipts.	Increase per cent.		Tonnage.	Increase per cent.	
			In Ten Years.	Per Annum.		In Ten Years.	Per Annum.		In Ten Years.	Per Annum.
		Miles.	Per cent.	Per cnt.	£.	Per cent.	Per cnt.	Tonnage.	Per cent.	Per cent.
London and North-Western . .	1864	1,191	..	..	5,569,117	..	..	12,049,545	..	..
	1874	1,556	30·65	2·71	8,841,711	58·76	4·73	24,017,638	99·33	7·14
North-Eastern	1864	1,095	..	..	3,013,286	..	..	16,234,624	..	..
	1874	1,374½	25·52	2·30	6,241,470	107·13	7·55	32,158,730	98·09	7·08
Midland	1864	663	..	..	2,550,535	..	..	8,849,430	..	..
	1874	1,090¼	64·44	5·10	5,602,498	119·66	8·19	18,876,004	113·30	7·87
London and South-Western . .	1864	505	..	..	1,339,940	..	..	882,205	..	..
	1874	665½	31·78	2·80	2,127,149	58·75	4·73	1,989,642	125·53	8·47
Great Northern	1864	421	..	..	1,757,667	..	..	2,035,269	..	..
	1874	557¾	32·48	2·85	2,763,628	57·23	4·63	5,644,520	177·34	10·74
Lancashire and Yorkshire	1864	381	..	..	1,978,045	..	..	6,109,959	..	..
	1874	396¼	4·00	0·39	3,269,716	65·30	5·16	11,085,086	81·43	6·14
South-Eastern	1864	279	..	..	1,138,968	..	..	690,901	..	..
	1874	337½	20·97	1·92	1,722,637	51·24	4·22	1,184,871	71·49	5·54
London and Brighton	1864	241½	..	..	946,059	..	..	897,736	..	..
	1874	347½	43·89	3·71	1,609,103	70·08	5·46	1,547,541	72·38	5·60
Manchester and Sheffield . . .	1864	242¼	..	..	766,283	..	..	2,537,191	..	..
	1874	259½	7·12	0·69	1,574,984	105·54	7·47	8,094,834	219·05	12·30

TABLE 2.—INCREASE in COST of MAINTENANCE and RENEWALS of PERMANENT WAY DURING the TEN YEARS 1865–1875.

Name of Railway.	Increase per cent. of							
	Cost of Staff.		Wages.		Material.		Total Cost.	
	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
London and North-Western . . .	34·42	36·36	52·56	46·04	81·33	73·47	64·01	65·46
North-Eastern . .	−13·61	−15·11	59·22	57·75	72·69	70·95	71·62	69·89
Midland	47·79	52·97	51·46	51·52	91·95	91·78	63·86	69·87
London and South-Western	53·61	54·52	Not	given	separ	ately.	27·42	25·52
Great Northern . .	−18·54	−19·10	69·56	69·23	50·14	50·18	49·00	48·81
Lancashire and York-shire	2·73	2·19	30·55	29·71	48·26	48·83	35·47	34·76
South-Eastern . .	43·14	43·86	−0·15	−2·70	45·93	43·96	1·69	3·54
London, Brighton and South Coast . .	−39·18	−37·10	6·04	6·60	77·18	77·47	34·74	37·20
Manchester, Sheffield and Lincolnshire .	47·35	40·10	34·34	29·84	73·01	69·89	66·68	59·97

TABLE 3.—COST per MILE of RAILWAY and per MILE of SINGLE LINE, during the last TEN YEARS, of the VARIOUS ITEMS included under the head of "MAINTENANCE and RENEWALS of PERMANENT WAY."

Half Years.	London and North-Western.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	1,215	2,217¾	13·82	7·58	..	..	..	..	202·82	111·12	June 1865.
Dec. " . . .	1,233	2,263¼	13·50	7·36	..	..	..	..	299·62	163·22	Dec. "
June 1866 . . .	1,233	2,263¼	15·54	8·46	..	..	..	..	199·63	108·76	June 1866.
Dec. " . . .	1,233	2,303¼	15·16	8·12	..	..	..	..	324·13	173·50	Dec. "
June 1867 . . .	1,279	2,334¼	14·76	8·08	..	..	..	..	222·95	122·16	June 1867.
Dec. " . . .	1,325	2,352½	14·36	8·08	..	..	..	..	335·08	188·74	Dec. "
June 1868 . . .	1,371	2,399¾	14·07	8·04	..	..	..	..	184·43	105·42	June 1868.
Dec. " . . .	1,416½	2,422¾	13·68	8·00	121·90	71·28	160·44	93·80	296·02	173·06	Dec. "
June 1869 . . .	1,423¾	2,424½	14·16	8·32	91·34	53·64	88·54	51·98	194·04	113·94	June 1869.
Dec.	1,477	2,465¾	14·73	8·82	112·45	67·36	177·60	106·38	304·78	182·56	Dec. "
June 1870 . . .	1,481	2,496½	14·76	8·76	86·23	51·16	94·50	56·06	195·49	115·98	June 1870.
Dec. " . . .	1,506½	2,561½	14·26	8·38	131·46	77·32	188·08	110·62	333·80	196·32	Dec. "
June 1871 . . .	1,506½	2,559	15·11	8·90	87·35	51·42	88·59	52·16	191·05	112·48	June 1871.
Dec. " . . .	1,514½	2,570½	15·14	8·92	121·83	71·78	205·36	121·00	342·33	201·70	Dec. "
June 1872 . . .	1,517	2,595¾	15·94	9·32	126·41	73·88	71·47	41·76	213·82	124·96	June 1872.
Dec. " . . .	1,532½	2,644	15·31	8·88	139·26	80·72	208·86	121·06	363·43	210·66	Dec. "
June 1873 . . .	1,537¾	2,666	15·91	9·18	147·96	85·34	123·22	71·08	287·09	165·58	June 1873.
Dec. " . . .	1,556¼	2,715¾	16·50	9·46	163·12	93·48	290·53	166·48	470·15	269·42	Dec. "
June 1874 . . .	1,556¼	2,726½	18·64	10·64	151·94	86·72	154·11	87·96	324·69	185·32	June 1874.
Dec. " . . .	1,556¼	2,747	17·72	10·04	160·88	91·14	426·31	241·52	604·91	342·70	Dec. "
June 1875 . . .	1,560	2,747	19·00	10·78	154·55	87·68	133·28	75·68	306·83	174·24	June 1875.
Dec. " . . .	1,564½	2,828¾	18·79	10·38	173·83	96·14	376·83	208·42	569·45	314·94	Dec. "
Average . . .	..	..	15·49	8·84	131·37	75·94	185·85	107·06	307·53	175·31	Average.

$$^{1}\ \frac{\pounds\ 1{,}395\cdot67}{175\cdot31} = 7\cdot96 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	Lancashire and Yorkshire.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	382	739¼	13·71	7·09	..	..	..	..	431·97	223·21	June 1865.
Dec. "	382	739¼	14·57	7·53	..	..	..	..	298·39	154·19	Dec. "
June 1866	382	739¼	14·91	7·71	..	..	..	..	263·29	136·05	June 1866.
Dec. "	382	739¼	16·86	8·71	..	..	..	..	468·88	242·29	Dec. "
June 1867	382	739¼	13·89	7·18	..	..	..	..	276·16	142·70	June 1867.
Dec. "	383½	742¼	15·01	7·76	..	..	..	..	521·87	269·64	Dec. "
June 1868	383½	742¼	14·85	7·67	..	..	..	..	272·91	141·01	June 1868.
Dec. "	384¾	743½	13·87	7·18	127·99	66·23	451·87	233·84	593·73	307·25	Dec. "
June 1869	384¾	743½	13·97	7·23	121·13	62·68	129·96	67·25	265·06	137·16	June 1869.
Dec. "	390¾	752	13·68	7·11	121·20	62·98	327·45	170·15	462·33	240·23	Dec. "
June 1870	390¾	752	14·96	7·77	118·63	61·64	127·96	66·49	261·55	135·90	June 1870.
Dec. "	396¼	758½	14·19	7·41	116·07	60·63	300·00	156·72	430·26	224·77	Dec. "
June 1871	396¼	758½	14·06	7·35	115·07	60·11	126·18	65·92	255·31	133·38	June 1871.
Dec. "	396¼	758½	13·50	7·05	128·96	67·37	319·54	166·93	462·00	241·35	Dec. "
June 1872	396¼	758½	14·65	7·65	131·45	68·67	126·18	65·92	272·28	142·24	June 1872.
Dec. "	396¼	758½	14·96	7·82	136·69	71·41	213·67	111·62	365·32	190·84	Dec. "
June 1873	396¼	758½	15·71	8·21	142·28	74·33	126·18	65·92	284·17	148·45	June 1873.
Dec. "	396¼	758½	15·43	8·06	146·90	76·74	462·32	241·52	624·65	326·32	Dec. "
June 1874	396¼	770¼	14·74	7·58	146·71	75·47	126·18	64·91	287·63	147·97	June 1874.
Dec. "	396¼	770¼	15·83	8·15	139·48	71·76	546·56	281·18	701·87	361·08	Dec. "
June 1875	397¾	773¼	14·74	7·58	164·73	84·73	125·71	64·66	305·18	156·98	June 1875.
Dec. "	437¼	851	13·70	7·04	158·75	81·57	458·34	235·50	630·79	324·10	Dec. "
Average	..	..	14·62	7·58	134·41	69·75	264·54	137·23	397·07	205·78	Average.

$$\frac{\overset{\text{£. dec.}}{^{1}\,1{,}395\cdot67}}{205\cdot78} = 6\cdot78 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	North-Eastern. Mile of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges. Per Mile of Railway.	Staff and Office Charges. Per Mile of Single Line.	Wages. Per Mile of Railway.	Wages. Per Mile of Single Line.	Materials. Per Mile of Railway.	Materials. Per Mile of Single Line.	Total. Per Mile of Railway.	Total. Per Mile of Single Line.	Half Years.
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	1,110	1,802¼	15·16	9·34	..	..	..	..	160·22	98·66	June 1865.
Dec. " . . .	1,207¾	1,946¾	14·20	8·80	..	..	..	..	198·68	123·26	Dec. "
June 1866 . . .	1,207¾	1,946¾	15·30	9·50	..	..	..	..	175·88	109·12	June 1866.
Dec. " . . .	1,220¾	1,959¾	14·26	8·88	..	..	..	..	190·58	118·72	Dec. "
June 1867 . . .	1,229	1,978	14·32	8·90	..	..	..	..	109·26	67·88	June 1867.
Dec. " . . .	1,242	2,010	14·32	8·84	..	..	..	..	248·90	153·82	Dec. "
June 1868 . . .	1,246	2,018	13·74	8·48	..	..	..	..	114·96	70·98	June 1868.
Dec. " . . .	1,254	2,029¾	7·26	4·50	84·52	52·22	164·70	101·74	256·48	158·44	Dec. "
June 1869 . . .	1,260	2,041¾	8·48	5·32	75·16	46·38	52·24	32·24	135·88	83·84	June 1869.
Dec. " . . .	1,275	2,071¾	8·94	5·50	85·96	52·90	157·72	97·06	252·62	155·46	Dec. "
June 1870 . . .	1,275	2,071¾	9·58	5·90	77·26	47·54	58·66	36·10	145·50	89·54	June 1870.
Dec. " . . .	1,281¼	2,079	9·54	5·88	94·88	58·48	169·52	104·48	273·94	168·84	Dec. "
June 1871 . . .	1,308¾	2,133½	9·26	5·68	81·82	50·18	55·20	33·86	146·28	89·74	June 1871.
Dec. " . . .	1,314	2,139	10·42	6·40	103·06	63·32	166·56	102·32	280·04	172·04	Dec. "
June 1872 . . .	1,325½	2,162	9·24	5·66	96·32	59·06	61·90	37·96	167·46	102·66	June 1872.
Dec. " . . .	1,329½	2,170	9·94	6·10	120·44	73·80	178·72	109·50	309·10	189·38	Dec. "
June 1873 . . .	1,331	2,173	10·72	6·54	111·70	68·42	90·32	55·32	212·74	130·28	June 1873.
Dec. " . . .	1,332	2,175	11·56	7·08	139·88	85·66	181·20	110·96	332·64	203·70	Dec. "
June 1874 . . .	1,337¼	2,180¼	12·08	7·40	121·48	74·50	131·02	80·36	264·58	162·28	June 1874.
Dec. " . . .	1,379	2,282	12·12	7·32	146·82	88·72	274·18	165·68	433·12	261·72	Dec. "
June 1875 . . .	1,400½	2,304	11·52	7·00	127·22	77·32	141·62	73·92	260·36	158·26	June 1875.
Dec. " . . .	1,400½	2,304	12·16	7·38	154·64	94·00	268·40	163·14	435·20	264·54	Dec. "
Average . . .	..	..	11·55	7·11	108·08	66·17	142·13	86·98	232·01	142·42	Average.

$$\frac{^{1}\ 1{,}395\cdot67\ (\pounds.\ \text{dec.})}{142\cdot42} = 9\cdot80 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	Lancashire and Yorkshire.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	382	739¼	13·71	7·09	..	..	..	..	431·97	223·21	June 1865.
Dec. " . . .	382	739¼	14·57	7·53	..	..	..	..	298·39	154·19	Dec. "
June 1866 . . .	382	739¼	14·91	7·71	..	..	..	..	263·29	136·05	June 1866.
Dec. " . . .	382	739¼	16·86	8·71	..	..	..	..	468·88	242·29	Dec. "
June 1867 . . .	382	739¼	13·89	7·18	..	..	..	..	276·16	142·70	June 1867.
Dec. " . . .	383½	742¼	15·01	7·76	..	..	..	..	521·87	269·64	Dec. "
June 1868 . . .	383½	742¼	14·85	7·67	..	..	..	..	272·91	141·01	June 1868.
Dec. " . . .	384¾	743½	13·87	7·18	127·99	66·23	451·87	233·84	593·73	307·25	Dec. "
June 1869 . . .	384¾	743½	13·97	7·23	121·13	62·68	129·96	67·25	265·06	137·16	June 1869.
Dec. " . . .	390¾	752	13·68	7·11	121·20	62·98	327·45	170·15	462·33	240·23	Dec. "
June 1870 . . .	390¾	752	14·96	7·77	118·63	61·64	127·96	66·49	261·55	135·90	June 1870.
Dec. " . . .	396¼	758½	14·19	7·41	116·07	60·63	300·00	156·72	430·26	224·77	Dec. "
June 1871 . . .	396¼	758½	14·06	7·35	115·07	60·11	126·18	65·92	255·31	133·38	June 1871.
Dec. " . . .	396¼	758½	13·50	7·05	128·96	67·37	319·54	166·93	462·00	241·35	Dec. "
June 1872 . . .	396¼	758½	14·65	7·65	131·45	68·67	126·18	65·92	272·28	142·24	June 1872.
Dec. " . . .	396¼	758½	14·96	7·82	136·69	71·41	213·67	111·62	365·32	190·84	Dec. "
June 1873 . . .	396¼	758½	15·71	8·21	142·28	74·33	126·18	65·92	284·17	148·45	June 1873.
Dec. " . . .	396¼	758½	15·43	8·06	146·90	76·74	462·32	241·52	624·65	326·32	Dec. "
June 1874 . . .	396¼	770¼	14·74	7·58	146·71	75·47	126·18	64·91	287·63	147·97	June 1874.
Dec. " . . .	396¼	770¼	15·83	8·15	139·48	71·76	546·56	281·18	701·87	361·08	Dec. "
June 1875 . . .	397¾	773¼	14·74	7·58	164·73	84·73	125·71	64·66	305·18	156·98	June 1875.
Dec. " . . .	437¼	851	13·70	7·04	158·75	81·57	458·34	235·50	630·79	324·10	Dec. "
Average . . .	..	..	14·62	7·58	134·41	69·75	264·54	137·23	397·07	205·78	Average.

[1] $\dfrac{\pounds.\ \text{dec.}\ 1{,}395 \cdot 67}{205 \cdot 78}$ = 6·78 years' average money life.

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	NORTH-EASTERN.										Half Years.
	Mile of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	1,110	1,802¼	15·16	9·34	..	..	..	..	160·22	98·66	June 1865.
Dec. " . . .	1,207¾	1,946¾	14·20	8·80	..	..	..	..	198·68	123·26	Dec. "
June 1866 . . .	1,207¾	1,946¾	15·30	9·50	..	..	..	..	175·88	109·12	June 1866.
Dec. " . . .	1,220¾	1,959¾	14·26	8·88	..	..	..	..	190·58	118·72	Dec. "
June 1867 . . .	1,229	1,978	14·32	8·90	..	..	..	..	109·26	67·88	June 1867.
Dec. " . . .	1,242	2,010	14·32	8·84	..	..	..	..	248·90	153·82	Dec. "
June 1868 . . .	1,246	2,018	13·74	8·48	..	..	..	..	114·96	70·98	June 1868.
Dec. " . . .	1,254	2,029¾	7·26	4·50	84·52	52·22	164·70	101·74	256·48	158·44	Dec. "
June 1869 . . .	1,260	2,041¾	8·48	5·32	75·16	46·38	52·24	32·24	135·88	83·84	June 1869.
Dec. " . . .	1,275	2,071¾	8·94	5·50	85·96	52·90	157·72	97·06	252·62	155·46	Dec. "
June 1870 . . .	1,275	2,071¾	9·58	5·90	77·26	47·54	58·66	36·10	145·50	89·54	June 1870.
Dec. " . . .	1,281¼	2,079	9·54	5·88	94·88	58·48	169·52	104·48	273·94	168·84	Dec. "
June 1871 . . .	1,308¾	2,133½	9·26	5·68	81·82	50·18	55·20	33·86	146·28	89·74	June 1871.
Dec. " . . .	1,314	2,139	10·42	6·40	103·06	63·32	166·56	102·32	280·04	172·04	Dec. "
June 1872 . . .	1,325½	2,162	9·24	5·66	96·32	59·06	61·90	37·96	167·46	102·66	June 1872.
Dec. " . . .	1,329½	2,170	9·94	6·10	120·44	73·80	178·72	109·50	309·10	189·38	Dec. "
June 1873 . . .	1,331	2,173	10·72	6·54	111·70	68·42	90·32	55·32	212·74	130·28	June 1873.
Dec. " . . .	1,332	2,175	11·56	7·08	139·88	85·66	181·20	110·96	332·64	203·70	Dec. "
June 1874 . . .	1,337¼	2,180¼	12·08	7·40	121·48	74·50	131·02	80·36	264·58	162·28	June 1874.
Dec. " . . .	1,379	2,282	12·12	7·32	146·82	88·72	274·18	165·68	433·12	261·72	Dec. "
June 1875 . . .	1,400½	2,304	11·52	7·00	127·22	77·32	141·62	73·92	260·36	158·26	June 1875.
Dec. " . . .	1,400½	2,304	12·16	7·38	154·64	94·00	268·40	163·14	435·20	264·54	Dec. "
Average . . .	..	..	11·55	7·11	108·08	66·17	142·13	86·98	232·01	142·42	Average.

$$\frac{{}^{1}\ \pounds.\ 1{,}395\cdot67\ \text{dec.}}{142\cdot42} = 9\cdot80 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued*.

Half Years.	South-Eastern.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	286¾	573½	7·58	3·80	..	..	..	..	264·16	132·08	June 1865.
Dec. "	286¾	573½	5·26	2·64	..	..	..	..	288·22	144·12	Dec. "
June 1866	286¾	573½	4·63	2·32	..	..	..	..	296·34	148·18	June 1866.
Dec. "	286¾	573½	6·32	3·16	..	..	..	..	287·06	143·52	Dec. "
June 1867	286¾	573½	5·48	2·74	..	..	..	..	288·80	144·40	June 1867.
Dec. "	308½	617	4·99	2·50	..	..	..	..	248·28	124·14	Dec. "
June 1868	308½	617	6·89	3·44	..	..	..	..	289·35	144·68	June 1868.
Dec. "	336½	654¼	6·75	3·46	152·53	78·46	83·12	42·76	242·40	124·68	Dec. "
June 1869	336½	654¼	8·91	4·58	159·40	81·98	84·51	43·46	252·82	130·02	June 1869.
Dec. "	336½	654¼	7·89	4·06	155·18	79·82	94·17	48·44	257·24	132·32	Dec. "
June 1870	336½	654¼	6·16	3·18	155·17	79·82	52·63	27·06	213·96	110·06	June 1870.
Dec. "	336½	654¼	5·25	2·70	149·86	77·08	52·76	27·14	207·87	106·92	Dec. "
June 1871	336½	654¼	5·95	3·06	146·83	75·52	69·61	35·80	222·39	114·38	June 1871.
Dec. "	336½	654¼	6·18	3·18	147·80	76·02	66·45	34·18	220·43	113·38	Dec. "
June 1872	336½	654¼	5·83	3·00	145·46	74·82	59·15	30·42	210·44	108·24	June 1872.
Dec. "	336½	654¼	6·43	3·30	152·92	78·66	71·94	37·00	231·29	118·96	Dec. "
June 1873	337½	656¼	5·97	3·08	164·91	84·80	83·96	43·18	254·84	131·06	June 1873.
Dec. "	337½	656¼	7·70	3·96	153·83	79·10	112·91	58·06	274·44	141·12	Dec. "
June 1874	337½	656¼	7·32	3·76	148·09	76·16	140·78	72·40	296·19	152·32	June 1874.
Dec. "	337½	656¼	7·21	3·70	149·30	76·78	115·15	59·22	271·66	139·70	Dec. "
June 1875	328½	654½	7·90	3·96	154·26	77·42	115·85	58·14	278·01	139·52	June 1875.
Dec. "	328½	654½	8·90	4·46	157·69	79·14	92·27	46·32	258·86	129·92	Dec. "
Average	..	..	6·61	3·37	152·88	78·37	86·35	40·24	257·05	130·63	Average.

$$\frac{{}^{1}\,£1{,}395\cdot 67}{130\cdot 63} = 10\cdot 68 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

MIDLAND.

Half Years.	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		Half Years.
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	687¾	1,325¼	10·08	5·24	..	..	..	..	217·96	113·12	June 1865.
Dec. "	687¾	1,325¼	10·60	5·50	..	..	..	..	275·38	142·90	Dec. "
June 1866	742¼	1,393½	9·58	5·10	..	..	..	..	256·28	136·50	June 1866.
Dec. "	742¼	1,393½	8·20	4·36	..	..	..	..	285·62	152·14	Dec. "
June 1867	796¾	1,461¾	9·32	5·08	..	..	..	..	269·00	146·62	June 1867.
Dec. "	796¾	1,461¾	8·54	4·66	..	..	..	..	302·20	164·72	Dec. "
June 1868	864½	1,583½	8·96	4·88	..	..	..	..	251·44	137·28	June 1868.
Dec. "	864½	1,583½	8·54	4·66	113·04	61·72	116·96	63·86	238·56	130·24	Dec. "
June 1869	875¼	1,594¼	9·08	4·98	109·44	60·08	89·90	49·35	208·42	114·42	June 1869.
Dec. "	890¼	1,624¼	10·03	5·50	117·20	64·24	123·38	67·62	250·61	137·36	Dec. "
June 1870	914¾	1,673¼	11·04	6·04	108·14	59·12	97·28	53·18	216·46	118·34	June 1870.
Dec. "	932½	1,703½	11·52	6·31	119·77	65·56	129·83	71·07	261·12	142·94	Dec. "
June 1871	938¾	1,710¾	13·35	7·33	119·11	65·36	125·18	68·69	257·64	141·37	June 1871.
Dec. "	953¼	1,733½	11·97	6·58	135·10	74·29	186·69	102·66	333·76	183·54	Dec. "
June 1872	965½	1,745¾	13·94	7·71	141·34	78·17	145·10	80·25	300·38	166·13	June 1872.
Dec. "	980¼	1,768¾	12·71	7·04	173·26	96·02	175·40	97·21	361·37	200·27	Dec. "
June 1873	1,005¾	1,816¼	15·09	8·36	169·77	94·01	229·16	126·90	414·02	229·26	June 1873.
Dec. "	1,011½	1,847¼	13·16	7·21	191·55	104·89	260·33	142·55	465·04	254·64	Dec. "
June 1874	1,035½	1,887½	15·42	8·46	168·04	92·19	247·12	135·57	430·58	236·22	June 1874.
Dec. "	1,090¼	1,980¼	15·18	8·36	166·83	91·85	221·93	122·19	403·94	222·39	Dec. "
June 1875	1,104¼	2,008½	17·12	9·41	175·27	96·36	225·35	123·90	417·74	229·67	June 1875.
Dec. "	1,106¾	2,025¼	14·80	8·09	186·64	101·99	228·82	125·04	430·26	235·12	Dec. "
Average	..	..	11·74	6·40	146·30	80·39	173·50	95·34	311·26	169·78	Average.

[1] $\frac{\text{£. dec. } 1{,}395 \cdot 67}{169 \cdot 78} = 8 \cdot 22$ years' average money life.

800 miles of siding.

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	London, Brighton and South Coast.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	241½	451¾	10·50	5·61	..	..	..	..	185·26	99·04	June 1865.
Dec. "	247½	457¾	10·76	5·90	..	..	..	..	225·68	123·64	Dec. "
June 1866 . . .	247¾	462	11·44	6·13	..	..	..	..	238·60	127·96	June 1866.
Dec. "	269¾	488½	10·40	5·74	..	..	..	..	252·34	139·34	Dec. "
June 1867 . . .	269¾	488½	10·70	5·91	..	..	..	..	274·44	151·55	June 1867.
Dec. "	293	529¾	10·68	5·91	..	..	..	..	362·04	200·24	Dec. "
June 1868 . . .	310¾	565¼	11·12	6·11	..	..	..	..	245·64	135·04	June 1868.
Dec. "	312½	569	10·64	5·84	123·48	67·82	116·06	63·74	250·18	137·40	Dec. "
June 1869 . . .	312½	569	10·62	5·83	118·76	65·22	78·02	42·85	207·40	113·90	June 1869.
Dec. "	334¾	609¾	6·06	3·33	116·84	64·14	74·56	40·93	197·46	108·40	Dec. "
June 1870 . . .	334¾	609¾	6·32	3·47	130·60	71·70	96·62	53·04	233·54	128·21	June 1870.
Dec. "	334¾	609¾	6·54	3·59	119·40	65·55	97·36	53·45	223·30	122·59	Dec. "
June 1871 . . .	336¾	613¾	6·58	3·61	121·74	66·80	108·38	59·47	236·70	129·88	June 1871.
Dec. "	341¾	622	6·50	3·57	118·82	65·28	92·92	51·05	218·24	119·90	Dec. "
June 1872 . . .	346¼	626¼	6·84	3·78	124·08	68·60	64·62	35·73	195·54	108·11	June 1872.
Dec. "	347½	628¾	6·34	3·50	125·20	69·19	67·56	37·34	199·10	110·03	Dec. "
June 1873 . . .	347½	628¾	6·36	3·52	124·04	68·55	90·82	50·19	221·22	122·26	June 1873.
Dec. "	347½	628¾	6·20	3·43	117·84	65·13	141·42	78·16	265·46	146·72	Dec. "
June 1874 . . .	347½	628¾	6·00	3·32	124·45	68·78	142·83	78·94	273·28	151·04	June 1874.
Dec. "	347½	628¾	5·77	3·19	123·98	68·52	128·61	71·08	258·36	142·79	Dec. "
June 1875 . . .	347½	628¾	6·65	3·68	125·54	69·38	132·11	73·01	264·30	146·07	June 1875.
Dec. "	347½	630½	6·67	3·68	123·77	68·22	106·87	58·90	237·31	130·80	Dec. "
Average . . .	..	..	8·17	4·48	122·57	67·54	102·59	56·52	239·33	131·59[1]	Average.

$$\frac{\text{£. dec.} \; {}^{1}\,1{,}395\cdot67}{131\cdot59} = 10\cdot61 \text{ years' average money life.}$$

200 miles of siding.

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	London and South-Western.										Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges.		Wages.		Materials.		Total.		
			Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	506¾	..	3·36	..					226·66	..	June 1865.
Dec. " . . .	506¾	..	3·41	..					233·71	..	Dec. "
June 1866 . . .	533½	..	3·26	..					257·50	..	June 1866.
Dec. " . . .	554½	..	3·42	..					277·04	..	Dec. "
June 1867 . . .	554½	..	3·54	..					243·82	..	June 1867.
Dec. " . . .	578¾	..	3·56	..					264·50	..	Dec. "
June 1868 . . .	578¾	..	3·62	..					247·70	..	June 1868.
Dec. " . . .	604	1,027	3·40	2·00					358·14	151·82	Dec. "
June 1869 . . .	604	1,027	3·47	2·04					215·44	126·70	June 1869.
Dec. " . . .	608	996	3·34	2·04	Wages and Materials not given separately in the Reports.				254·83	155·56	Dec. "
June 1870 . . .	624	1,030	2·98	1·80					198·27	120·12	June 1870.
Dec. " . . .	624	1,036	3·21	1·94					227·35	136·94	Dec. "
June 1871 . . .	633	1,051	5·31	3·20					191·03	115·06	June 1871.
Dec. " . . .	633	1,051	4·11	2·48					211·25	127·24	Dec. "
June 1872 . . .	633	1,051	4·55	2·74					213·95	128·86	June 1872.
Dec. " . . .	640	1,057	4·66	2·82					247·28	149·72	Dec. "
June 1873 . . .	640	1,057	5·26	3·18					259·24	156·96	June 1873.
Dec. " . . .	646	1,064	5·21	3·16					280·54	170·32	Dec. "
June 1874 . . .	650¾	1,068½	5·29	3·22					313·08	190·68	June 1874.
Dec. " . . .	665½	1,083¼	5·10	3·14					303·64	186·54	Dec. "
June 1875 . . .	665½	1,094¾	5·25	3·20					259·85	157·96	June 1875.
Dec. " . . .	674¾	1,104	5·03	3·08					312·33	190·90	Dec. "
Average . . .	..	..	4·11	2·67	..	..	..	..	254·41	151·02	Average.

$$\frac{\overset{\pounds.\ \text{dec.}}{1{,}395\cdot67}}{151\cdot02}\ ^{1} = 9\cdot21 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	MANCHESTER, SHEFFIELD AND LINCOLNSHIRE. Miles of Railway.	Equivalent in Miles of Single Line.	Staff and Office Charges. Per Mile of Railway.	Staff and Office Charges. Per Mile of Single Line.	Wages. Per Mile of Railway.	Wages. Per Mile of Single Line.	Materials. Per Mile of Railway.	Materials. Per Mile of Single Line.	Total. Per Mile of Railway.	Total. Per Mile of Single Line.	Half Years.
	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865 . . .	242¼	441¾	9·00	4·94	..	..	..	..	191·00	104·74	June 1865.
Dec. „ . . .	246	449¼	9·00	4·93	..	..	..	..	215·00	117·73	Dec. „
June 1866 . . .	246	449¼	10·00	5·48	..	..	..	..	205·00	112·25	June 1866.
Dec. „ . . .	246	449¼	10·00	5·48	..	..	..	..	210·00	114·99	Dec. „
June 1867 . . .	246	449¼	11·00	6·02	..	..	..	..	203·00	111·16	June 1867.
Dec. „ . . .	246	449¼	10·00	5·48	..	..	..	..	197·00	107·87	Dec. „
June 1868 . . .	249	455¼	12·00	6·56	..	..	..	..	182·00	99·55	June 1868.
Dec. „ . . .	258¾	474¾	11·00	6·00	88·00	47·96	115·00	62·68	214·00	116·64	Dec. „
June 1869 . . .	258¾	488	12·00	6·36	87·00	46·13	129·00	68·40	228·00	120·89	June 1869.
Dec. „ . . .	260¾	489½	11·00	5·86	86·00	45·81	140·00	74·58	237·00	126·25	Dec. „
June 1870 . . .	254¼	473½	11·00	5·91	79·00	42·42	151·00	81·08	241·00	129·41	June 1870.
Dec. „ . . .	254¼	473½	10·00	5·31	79·00	42·42	134·00	71·95	223·00	119·68	Dec. „
June 1871 . . .	254¼	473½	13·00	7·20	82·00	43·88	120·00	64·28	215·00	115·36	June 1871.
Dec. „ . . .	257¾	490¼	12·00	6·31	84·00	44·16	144·00	75·71	240·00	126·18	Dec. „
June 1872 . . .	257¾	490¼	13·00	6·83	87·00	45·74	149·00	78·34	249·00	130·91	June 1872.
Dec. „ . . .	257¾	490¼	13·00	6·83	96·00	50·47	223·00	117·24	332·00	174·54	Dec. „
June 1873 . . .	257¾	490¼	13·00	6·83	101·00	53·10	320·00	168·24	434·00	228·17	June 1873.
Dec. „ . . .	258¼	491½	12·00	6·31	108·00	56·75	349·00	183·38	469·00	246·44	Dec. „
June 1874 . . .	258¼	491½	12·99	6·83	110·55	58·09	296·62	155·85	420·16	220·77	June 1874.
Dec. „ . . .	259½	493¼	14·87	7·82	106·86	56·22	287·75	151·39	409·48	215·43	Dec. „
June 1875 . . .	259½	499½	13·27	6·89	113·18	58·80	201·80	104·84	328·25	170·53	June 1875.
Dec. „ . . .	259½	516¾	14·54	7·30	124·84	62·69	186·29	93·55	325·67	163·54	Dec. „
Average . . .	..	..	11·71	6·23	95·50	50·31	196·43	103·44	271·29	144·23	Average.

$$\frac{^{1}\,\pounds 1,395\cdot 67}{144\cdot 23} = 9\cdot 68 \text{ years' average money life.}$$

[1] Average cost of relaying during ten years.

TABLE 3—*continued.*

Half Years.	Great Northern.											Half Years.
	Miles of Railway.	Equivalent in Miles of Single Line.	Miles Relaid.	Staff and Office Charges.		Wages.		Materials.		Total.		
				Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	Per Mile of Railway.	Per Mile of Single Line.	
	Miles.	Miles.	Miles.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	£. dec.	
June 1865	434	769	48	19·88	11·22	70·93	40·02	113·86	64·27	204·67	115·51	June 1865.
Dec. "	440	781		18·50	10·42	73·83	41·60	181·81	102·43	274·14	154·45	Dec. "
June 1866	458	819	50¼	20·24	11·32	67·18	37·56	143·35	80·16	230·77	129·04	June 1866.
Dec. "	442	801		19·78	10·91	77·68	42·86	176·66	97·48	274·12	151·25	Dec. "
June 1867	442	801	56¾	17·74	9·79	73·82	40·74	152·91	84·38	244·47	134·91	June 1867.
Dec. "	442	801		18·30	10·10	86·94	47·98	155·04	85·55	260·28	143·63	Dec. "
June 1868	489	890	73¾	16·90	9·29	103·85	57·06	162·50	89·29	283·25	155·64	June 1868.
Dec. "	507	926		15·37	8·42	109·88	60·16	173·01	94·71	298·26	163·29	Dec. "
June 1869	507	926	62½	14·15	7·75	112·58	61·64	150·30	82·29	277·03	151·68	June 1869.
Dec. "	511	930		13·69	7·52	109·68	60·27	141·63	77·82	265·00	145·61	Dec. "
June 1870	511	930	44½	15·07	8·28	110·83	60·90	127·48	70·05	253·38	139·23	June 1870.
Dec. "	511	930		15·47	8·50	117·21	64·40	129·90	71·38	262·58	144·28	Dec. "
June 1871	511	930	53½	14·94	8·21	115·93	63·70	159·89	87·85	290·76	159·76	June 1871.
Dec. "	511	930		16·14	8·87	119·74	65·79	141·20	77·58	277·08	152·24	Dec. "
June 1872	531½	954½	62¾	14·31	7·97	124·10	69·10	176·34	98·19	314·75	175·26	June 1872.
Dec. "	540¼	963¼		13·61	7·63	136·98	76·83	162·88	91·35	313·47	175·81	Dec. "
June 1873	551¼	976½	62¾	14·23	8·03	129·20	72·94	202·43	114·27	345·86	195·24	June 1873.
Dec. "	556¾	983½		12·85	7·27	142·73	80·80	246·75	139·69	402·33	227·76	Dec. "
June 1874	557¾	987½	68½	14·86	8·39	129·07	72·90	220·41	124·49	364·34	205·78	June 1874.
Dec. "	557¾	987½		14·28	8·07	134·56	76·00	263·39	148·76	412·23	232·83	Dec. "
June 1875	558¾	995¼	71¼	15·30	8·59	130·81	73·44	226·41	127·11	372·52	209·14	June 1875.
Dec. "	560¾	999¼		15·43	8·66	143·07	80·29	217·58	122·10	376·08	211·05	Dec. "
Average	..	..	..	15·96	8·87	110·03	61·23	173·89	96·87	299·88	166·97	Average.

[1] $\frac{£.\ dec.\ 1,395·67}{166·97}$ = 8·36 years' average money life.

[1] Average cost of relaying during ten years.

Table 3—*continued.*

Average Cost of Relaying 1 Mile of Single Line between 1865 and 1875.

Rails' average weight 80 lbs. Price £7 10*s.* per ton.

		Tons.	cwt.	£.	*s.*	*d.*	£.	*s.*	*d.*
Rails . . .	3,520 yards at 80 lbs. =	126	0 at	7	10	0 =	945	0	0
Chairs . .	4,024 „ 36 „ =	65	0 „	3	15	0 =	243	15	0
Fish plates .	503 pairs „ 24 „ =	5	10 „	7	10	0 =	41	5	0
Bolts . . .	2,012 „ „ 1½ „ =	1	7 „	10	15	0 =	14	10	3
Keys . . .	4,024		„	3	15	0 =	15	1	10
Trenails . .	8,048		„	3	15	0 =	30	3	8
Spikes . .	4,024	1	16 „	9	0	0 =	16	4	0
Sleepers . .	2,012		„	0	3	0 =	301	16	0
Labour . .	1,760 yards . . .		at per yard	0	0	11 =	80	13	4
							1,688	9	1[1]
Renewal of top ballast	. 1,792 yards at			0	3	6 =	224	0	0
							1,912	9	1

Credit:—

	Tons.	cwt.	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*
Old rails	105	6 at	3	15	0 =	394	17	6			
„ chairs	37	0 „	2	5	0 =	83	5	0			
Fish plates	4	19 „	6	17	6 =	34	0	8			
Wrought scrap iron . .	1	0 „	4	12	6 =	4	12	6			
									516	15	8
									1,395	13	5

[1] Cost of materials, ex. labour £1,608

The normal depreciation in a mile of permanent way would be $\frac{1,608}{3}$ = £536.

TABLE 4.—AMOUNT EXPENDED on MAINTENANCE and RENEWALS of PERMANENT WAY, and the AMOUNT of ORDINARY CAPITAL, for the YEAR 1875, for the NINE UNDERMENTIONED RAILWAYS.

Name of Railway.	Half Year.	Miles of Railway.	Equivalent Miles of Single Line.	Amount expended on Maintenance and Renewals of Permanent Way for the Year 1875.	Amount of Ordinary Capital, 1875.
		Miles.	Miles.	£.	£.
London and North-Western . . .	June Dec.	1,560 1,564½	2,747 2,828¾	239,324 445,451	31,126,007
North-Eastern . .	June Dec.	1,400½ 1,400½	2,304 2,304	182,308 304,743	17,183,124
Midland	June Dec.	1,104½ 1,106¾	2,008½ 2,025¼	230,645 238,101	18,800,388
London and South-Western . . .	June Dec.	665½ 674¾	1,094¾ 1,104	86,464 105,373	8,220,643
Great Northern . .	June Dec.	558¾ 560¾	995¼ 999¼	104,071 105,442	9,808,930
Lancashire and Yorkshire	June Dec.	397¾ 437¼	773¼ 851	60,691 137,909	14,116,482
South-Eastern . .	June Dec.	328½ 328½	654½ 654½	45,664 42,518	7,970,889
London and Brighton	June Dec.	347½ 347½	628¾ 630½	45,920 41,232	6,839,943
Manchester and Sheffield	June Dec.	259½ 259½	499½ 516¾	42,590 42,255	5,492,553
Total mileage of railway	(June half)	6,622½	11,705½	2,500,701	119,558,959

$$\text{Average cost per mile per annum } \frac{2,500,701}{11,705\cdot5} = £213\cdot64$$

$$\frac{\text{Cost of renewing 1 mile of single line with steel rails } £1,626\cdot283}{\text{Average annual cost of maintenance and renewals } 213\cdot64} = 7\cdot61 \text{ years' average "money life."}$$

TABLE 5.—LONDON and NORTH-WESTERN RAILWAY. CREWE STEEL RAILS. (For Sections, see Plate 18.)

—	Section.	Length of Rail.	Original Weight per Yard.	Present Weight per Yard.	Loss of Weight.	When laid down.	When turned.	When taken up.	Period in Work.	Estimated Tonnage.	Wear of Tables.	Number of Tons per $\frac{1}{16}$th Wear of Tables.
		Feet.	lbs.	lbs.	lbs.				Years.		Inch.	Tons.
Steel rails laid in up Main Line south of junction with Crewe Station platform siding	A	24	75	53·56	21·44	1863	1866	1875	12	120,000,000	0·625	12,000,000
	B	24	75	55·43	19·57	1863	1866	1875	12	120,000,000	0·625	12,000,000
Steel rail laid in Crewe Station up platform siding south end . . .	C	21	75	55	20	1863	1866	1875	12	72,000,000	0·875	5,142,856
	D	24	75	55	20	1863	1866	1875	12	72,000,000	0·531	8,474,576
Steel rail laid in Crewe Station up platform siding, opposite south Tank House, March 10, 1863; taken up Oct. 1, 1872; laid down in same place and turned Oct. 30, 1872; re-turned to old face Nov. 21, 1872; again taken up March 17, 1873 (to which date the tonnage is taken) and sent to the Manchester Exhibition; put down to new face Dec. 3, 1873	E	34	75	Not ascertained.		1863	See remarks.		10	60,000,000	0·406	9,370,777

TABLE 6.—GREAT NORTHERN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE OVER STEEL RAILS near MAIDEN LANE and COPENHAGEN TUNNELS, together with a CHEMICAL ANALYSIS of the RAILS. (For Sections, see Plate 18.)

—	Copenhagen Tunnel. Down Line.	Maiden Lane Tunnel. Up Line.		North of Copenhagen Tunnel. Up Line.			
	No. 9.	No. 17.	No. 18.	No. 21.	No. 22.	No. 23.	No. 24.
Original weight per yard	75 lbs.	75 lbs.	75 lbs.	75 lbs.	75 lbs.	82 lbs.	82 lbs.
When laid down	Nov. 1866.	Feb. 1867.	Feb. 1867.	March 1867.	March 1867.	Nov. 1867.	Nov. 1867.
When turned	June 1869.	July 1870.	July 1870.	Feb. 1870.	Feb. 1870.	Nov. 1869.	Nov. 1869.
Rubbings taken	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.	Sept. 1875.
Period in work up to rubbings	8 yrs. 10 mths.	8 yrs. 7 mths.	8 yrs. 7 mths.	8 yrs. 6 mths.	8 yrs. 6 mths.	7 yrs. 10 mths.	7 yrs. 10 mths.
Gradients of line	Rising 1 in 10.	Falling 1 in 105.	Falling 1 in 105.	Falling 1 in 110.	Falling 1 in 110.	Falling 1 in 110.	Falling 1 in 110.
Tonnage passed over	96,824,000	40,329,000	40,329,000	63,868,000	63,868,000	59,638,000	59,638,000
Wear of tables	0·40	0·48	0·30	0·52	0·43	0·24	0·12
No. of tons per $\frac{1}{16}$th wear of tables	15,129,000	5,251,000	8,402,000	7,676,000	9,283,000	15,531,000	31,061,000
				Chemical Analysis by Mr. Riley.			
Carbon	0·336	0·331	0·296	0·302	* 0·538	0·340	† 0·270
Silicium	0·034	0·029	0·029	0·034	0·040	* 0·062	† 0·020
Sulphur	† 0·038	0·090	0·051	* 0·096	0·059	0·055	0·051
Phosphorus	0·125	0·186	0·144	0·162	0·111	* 0·242	† 0·100
Iron	99·408	99·451	99·637	99·632	99·249	99·223	99·475
Manganese	0·338	0·353	† 0·245	† 0·245	0·461	* 0·470	0·259
Copper	* 0·032	0·020	0·020	† 0·018	0·022	0·028	0·025
	100·311	100·460	100·422	100·489	100·480	100·425	100·200

Maximum percentage shown thus * Minimum percentage shown thus †

TABLE 7.—GREAT NORTHERN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE over STEEL RAILS, and a CHEMICAL ANALYSIS of the RAILS. (For Sections, see Plate 18.)

—	Between Hornsey and Wood Green. Up Line.	Between Barnet and Potters Bar. Up Line.	South of Potters Bar Station. Down Line.	South of Biggleswade. Up Line.		Through Biggleswade Station. Down Line.	South of Peterborough. Down Line.	North of Doncaster. Up Line.
	No. 10.	No. 22.	No. 24.	No. 64.	No. 55.	No. 66.	No. 84.	No. 6.
Original weight per yard	82 lbs.	..	72 lbs.	80 lbs.	80 lbs.	80 lbs.	80 lbs.	75 lbs.
When laid down .	Nov. 1867.	April 1872.	March 1867.	April 1874.	July 1873.	May 1871.	Feb. and Mar. 1871.	Oct. and Nov. 1865.
When turned . .	Not turned.	Qy. date.	← . . . . Not turned. . . . . →					August 1867.
Rubbings taken .	← . . . . March 1876. . . . . →							
Period in work up to rubbings . .	8 yrs. 4 mths.	3 yrs. 11 mths	9 years.	1 yr. 11 mths.	2 yrs. 9 mths.	4 yrs. 10 mths.	5 years.	10 yrs. 4 mths.
Gradients of line .	← . . . Falling 1 in 200. . . →			← Rising 1 in 330. →		Level.	Falling 1 in 605.	Rising 1 in 400.
Tonnage passed over	66,546,000	28,051,000	33,105,000	..	..	..	..	..
Wear of tables . .	0·15	0·13	0·10	..	..	..	..	..
No. of tons per $\frac{1}{16}$th wear of tables .	27,727,000	13,486,000	20,690,000	..	..	..	..	..
Chemical Analysis by Mr. Riley.								
Carbon	·320	·285	·319	·349	† ·158	·323	·241	* ·406
Silicium.	·037	† ·021	·077	·081	·046	* ·102	·037	·045
Sulphur.	·030	† ·029	·031	* ·089	·076	·060	·068	·046
Phosphorus. . . .	* ·193	* ·193	·090	·068	·074	·087	† ·064	·079
Iron	99·667	99·905	99·817	99·462	99·719	99·423	99·718	99·617
Manganese	·316	·273	·302	* ·576	† ·187	·446	·367	·359
Copper	* ·026	·029	·033	·033	·039	·033	·028	* ·046
	100 589	100·735	100·669	100·658	100·299	100·474	100·523	100·598
Character of material as found in drilling . . .	Moderately hard.	Very hard.	Very hard.	Soft.	Soft.	Hard.	Very soft.	Moderately hard.

Maximum percentage shown thus * Minimum percentage shown thus †

TABLE 8.—GREAT NORTHERN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE over STEEL RAILS.
(For Sections, see Plate 18.)

—	In Maiden Lane Tunnel, South End.		In Maiden Lane Tunnel, North End.	North of Maiden Lane Tunnel.		Between Maiden Lane and Copenhagen Tunnels.				Between Wood Green and Southgate.	
	Down Line.		Down Line.	Down Line.		Down Line.		Up Line.		Up Line.	
	A.	No. 1.	B.	No. 4.	No. 5.	No. 6.	No. 7.	No. 19.	No. 20.	No. 12.	At Southall Station Platform. No. 14.
Original weight per yard	lbs. 75	lbs. 75	lbs. 75	lbs. 75	lbs. 75	lbs. 82	lbs. 82	lbs. 82	lbs. 82	lbs. 82	lbs. 82
When laid down	September 1866.					March 1863.				Feb. and March 1868.	
When turned	3 times.		Once.	3 times.		Not turned.	Once.			Not turned.	
Rubbings taken	July 1871.	Aug. 1871.	Dec. 1870.	Mar. 1875.		August 1871.		May 1875.		April 1875.	
Period in work up to rubbings	4 yrs. 11 mo.	5 yrs.	4 yrs. 3 mo.	8 yrs. 6 mo.		8 years 5 months.		12 yrs. 2 mo.		7 years 2 months.	
Gradients of line	← . . . . Rising 1 in 105. . . . . →							Falling 1 in 105.		Falling 1 in 200.	
Tonnage passed over	64,780,000	66,224,000	12,865,000	32,694,000		22,093,000		42,927,000		51,923,000	
Wear of tables	0·58	0·42	0·32	0·40	0·38	0·11	0·19	0·26	0·25	0·32	0·40
No. of tons per $\frac{1}{16}$th wear of tables	6,981,000	9,855,000	2,513,000	5,239,000		12,553,000	7,267,000	10,521,000		10,141,000	8,113,000

TABLE 9.—METROPOLITAN RAILWAY. TABLE SHOWING the AMOUNT of WEAR and TONNAGE over STEEL RAILS, and a CHEMICAL ANALYSIS of the RAILS. (For Sections, see Plate 18.)

—	Between Praed Street and Bayswater.		Between Baker Street and Edgeware Road.		Between St. John's Wood Road and Marlborough Road.	Clerkenwell Tunnel.	
	Up Line.	Down Line.	Up Line.	Down Line.	Single Line.	Up Line.	
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6. Dry place.	No. 6a. Wet place.
When laid down .	Oct. 1868.	Oct. 1868.	June 1866.	June 1866.	April 1868.	June 1866.	June 1866.
When taken up. .	March 1876.	March 1876.	March 1876.	March 1876.	March 1876.	March 1876.	March 1876.
Period in work . .	7 years 4 months.		9 years 9 months.		7 yrs. 11 mths.	9 years 9 months.	
Gradients of line .	Rising 1 in 75.	Falling 1 in 75.	Falling 1 in100.	Rising 1 in 100.	1 in 60.	Falling 1 in 500.	
Tonnage passed over	32,086,470	32,086,470	89,105,900	89,105,900	46,623,568	99,889,140	99,889,140
Wear of tables . .	0·27	0·36	0·28	0·35	0·40	0·45	0·93
No. of tons per $\frac{1}{16}$th wear of tables. .	7,427,500	5,570,600	19,890,000	15,912,000	9,713,400	13,874,000	6,713,000
Chemical Analysis by Mr. Riley.							
Carbon	·317	·295	* ·679	† ·294	·316	·405	·423
Silicium	·046	·042	* ·640	·059	† ·026	·031	·046
Sulphur	·037	·040	·040	·037	* ·041	† ·030	·037
Phosphorus . . .	·111	·132	·067	·067	* ·133	† ·060	·087
Iron	99·637	99·587	98·896	99·620	99·756	99·529	99·475
Manganese . . .	·259	·403	* ·533	·310	† ·230	·389	·518
Copper	·032	·040	† ·030	† ·030	·058	* ·059	·052
	100·439	100·593	100·885	100·417	100·560	100·503	100·638

Maximum percentage shown thus * Minimum percentage shown thus †

TABLE 10.—SOUTH-EASTERN RAILWAY. WEAR of STEEL RAILS BETWEEN LONDON BRIDGE and CHARING CROSS STATIONS.

(For Sections, see Plate 18.)

—	Supplied by		
	The Railway Steel and Plant Company.	Ebbw Vale Company.	Landore Siemens Steel Co. (Limited).
	No. 1.	No. 2.	No. 3.
When laid down	August 1868.	August 1869.	April 1872.
Rubbings taken	Oct. 1875.	Oct. 1875.	Oct. 1875.
Period in work	7 yrs. 2 mths.	6 yrs. 2 mths.	3 yrs. 6 mths.
Tonnage passed over	30,786,000	37,228,000	31,394,000
Wear of top table	0·45	0·60	0·125
No. of tons per $\frac{1}{16}$th wear of tables	4,276,000	3,878,000	15,697,000

TABLE 11.—TAFF VALE RAILWAY. WEAR of STEEL RAILS.

(For Section, see Plate 18.)

—	Supplied by Messrs. J. Brown and Co., Sheffield.
When laid down	August 1863.
Rubbing taken	April 30, 1876.
Period in work	12 yrs. 8 months.
Tonnage passed over	63,289,000
Wear of tables	0·125
No. of tons per $\frac{1}{16}$th wear of tables	31,644,000

TABLE 15.—ANNUAL COST of RENEWALS of 1 MILE of SINGLE LINE of RAILWAY with STEEL RAILS (Credit being allowed for old materials). The Life of Steel Rails being Forty-two Years, Sleepers Eight Years.

No.	Description.	£.	s.	d.	— £.	s.	d.	— £.	s.	d.	Life in Years.	— £.	s.	d.
503	Steel rails, 21 ft., 3,521 yds. at 80 lbs. = 126 tons, at.	10	0	0	1,260	0	0							
	Do., credit, 3,520 yds. at 78 lbs. = 123 tons, at .	3	15	0	461	5	0	798	15	0	42	19	0	4
4,024	Chairs, 40 lbs. = 72 tons, at	4	10	0	324	0	0							
4,000	Credit old chairs, 28 lbs. = 50 tons, at.	2	5	0	112	10	0	211	10	0	42	5	0	9
Pairs. 503	Fish plates, 40 lbs. = 9 tons, at	8	15	0	78	15	0							
503	Do., credit old, 22 lbs. = 4 tons 19 cwt., at . .	4	10	0	22	5	0	56	9	6	15	3	15	4
2,012	Fish bolts, 1½ lbs. each = 1 ton 7 cwt., at . . .	17	0	0	22	19	0							
	Credit old scrap, 1 ton, at .	3	15	0	3	15	0	19	4	0	10	1	18	5
4,024	6-inch keys, at	3	15	0	15	1	10	15	1	10	3	5	0	7
8,048	Treenails, at	3	15	0	30	3	8	30	3	8	3	10	1	3
4,024	Spikes, 1 lb. each = 1 ton 16 cwt., at	14	0	0	25	4	0							
	Do., credit old scrap, 1 ton, at	3	15	0	3	15	0	21	9	0	6	3	11	6
2,012	Sleepers, each at	0	3	11	385	12	8	385	12	8	8	48	4	1
	Labour, 1,760 yards at. .	0	1	0	88	0	0	88	0	0	16	5	10	0
								1,626	5	8		102	2	3
C. yds. 1,792	Ballast (top ballast), at, including labour . . . = 11′ 0″ × 5,280 × 0′ 10″	0	2	6	224	0	0	224	0	0	[1] 50	4	9	7
								1,850	0	0		106	11	10

[1] NOTE.—The average annual cost of Ballast for Maintenance and Renewals of the Permanent Way during the last ten years was exactly £6·51 per mile of single line. Labour is taken at the mean of the lives of the different materials.

'SED under BENDING STRESS, per REPORTS A, C, D, and F.

	Thrusting Stress.				
	Cut out of Rail Top.				
	Stress.	Depression. Set, 1 inch.			
[N]o.	Elastic per Square Inch.	At 50,000 lbs. per Square Inch.	At 100,000 lbs. per Square Inch.	At 150,000 lbs. per Square Inch.	Appearance of Surface.
	lbs.	Per cent.	Per cent.	Per cent.	
24	58,000	0·0	3·3	13·9	Very slightly marked.
27	58,000	0·0	3·5	14·1	Do.
	58,000	0·0	3·4	14·0	Very slightly marked.
18	55,500	0·0	3·8	15·4	Very slightly marked.
21	55,000	0·0	4·1	16·3	Do.
	55,250	0·0	3·9	15·8	Very slightly marked.
28	66,000	0·0	3·4	15·6	Very slightly marked.
22	61,500	0·0	6·1	20·2	Do.
25	57,000	0·0	7·0	21·8	Do.
31	51,500	0·0	9·9	24·4	Do.
	59,000	0·0	6·6	20·5	Very slightly marked.
10	51,000	0·0	9·1	24·5	Very slightly marked.
13	49,000	0·3	9·3	25·1	Do.
16	49,000	0·3	9·3	25·1	Do.
19	48,000	0·5	9·8	25·2	Do.
	49,250	0·3	9·4	25·0	Very slightly marked.
67	54,000	0·0	5·1	18·8	Very slightly marked.
70	54,000	0·0	5·1	18·8	Do.
	54,000	0·0	5·1	18·8	Very slightly marked.

3	84,000	86,000	88,000	90,000	Stress, Deflections. Elastic.	Ultimate.	At 70,000	Ultimate.	Remarks.
					lbs.	lbs.	Inches.	Inches.	
	..	..	..	..	48,400	83,210	2·29	5·91	Snapped.
	..	..	..	..					
	..	..	..	..	48,100	82,510	2·40	10·0	Unbroken.
	..	..	..	..					
	..	..	..	..	42,200	75,390	4·80	10·0	Do.
	..	..	..	..					
	..	..	..	..	40,600	72,960	6·52	10·0	Do.
	..	..	..	..					
	..	..	..	..	44,825	78,517	4·00	8·98	
	..	..	..	..					
	..	..	..	..	38,800	73,970	6·30	10·0	Unbroken.
	..	..	..	..					
	..	..	..	..	36,500	73,420	6·50	10·0	Do.
	..	..	..	..					
	..	..	..	..	38,400	73,110	6·68	10·0	Do.
	..	..	..	..					
	..	..	..	..	37,500	72,880	6·81	10·0	Do.
	..	..	..	..					
	..	..	..	..	37,800	73,345	6·57	10·0	
	..	..	..	..					

...ESU RAILS TESTED under BENDING STRESS, per REPORT A, see above.

...Ulti...	Thrusting Stress. Cut out of Rail Top. Stress Elastic per Square Inch.	Depression. At 50,000 lbs. per Sq. Inch.	At 100,000 lbs. per Sq. Inch.	At 150,000 lbs. per Sq. Inch.	Appearance of Fracture.
Per	lbs.	Per cent.	Per cent.	Per cent.	
6	52,800	0·0	6·0	19·7	Very slightly marked.
20	46,200	0·6	8·6	24·7	Do.
13	49,500	0·3	7·3	22·2	Do.
17	49,000	0·3	6·6	21·6	Very slightly marked.
19	48,000	0·4	6·8	22·0	Do.
18	48,500	0·3	6·7	21·8	Do.

L

,000

96

54

25

see

t No.

K.
,647
,644

,434
,437

,955
,952

L Rail. Brand, and from whom received, see margin.

,000	70,000	Stress. Elastic.	Stress. Ultimate.	Deflection. At 60,000	Deflection. Ultimate.	Remarks.
		lbs.	lbs.	Inches.	Inches.	
..	..	34,600	67,820	5·26	10·0	Unbroken.
..	..	..	..	..	..	
..	..	39,200	59,630	..	2·86	Broke at sleeper hole, 13¾ inches from centre.
..	..	..	..	..	..	
..	..	34,300	64,180	5·17	10·0	Unbroken.
..	..	..	..	..	..	
..	..	33,500	62,420	5·92	10·0	Do.
..	..	..	..	..	..	
..	..	33,900	63,300	5·54	10·0	Unbroken.
..	..	..	..	..	..	
96	6·72	37,600	75,110	3·63	10·0	Unbroken.
.	..	..	..	..	..	
54	7·06	37,200	70,990	3·79	10·0	Do.
..	..	..	..	..	..	
25	6·89	37,400	73,050	3·71	10·0	Unbroken.
.	..	..	..	..	..	

, see above.

Thrusting Stress.

Cut out of Rail Top.

t No.	Elastic. Stress per Square Inch.	Depression. Sets, 1 Inch. At 50,000 lbs. per Square Inch.	Depression. Sets, 1 Inch. At 100,000 lbs. per Square Inch.	Depression. Sets, 1 Inch. At 150,000 lbs. per Square Inch.	Appearance of Surface.
K.	lbs.	Per cent.	Per cent.	Per cent.	
,647	59,000	0·0	4·2	17·3	Very slightly marked.
,644	52,000	0·0	8·8	23·8	Do.
	55,500	0·0	6·5	20·5	Very slightly marked.
,434	42,000	1·2	11·1	28·2	Very slightly marked.
,437	38,500	1·8	12·8	29·8	Do.
	40,250	1·5	11·9	29·0	Very slightly marked.
,955	44,500	0·8	7·4	23·0	Slightly marked.
,952	43,000	0·9	7·9	23·9	Do.
	43,750	0·8	7·6	23·4	Slightly marked.

TABLE 16.—NUMBER and GROSS WEIGHT of TRAINS PASSING OVER the DOWN LINE of the GREAT NORTHERN RAILWAY BETWEEN BARNET and POTTERS BAR, 1865 to 1875.

Year.	Trains.	Number.	Weight.	Total of all Trains per Annum. Number.	Total of all Trains per Annum. Weight.
		No.	Tons.	No.	Tons.
1865	Passenger.	10,140	1,192,500		
	Goods . .	14,430	2,159,586	24,570	3,352,086
1866	Passenger.	12,376	1,776,164		
	Goods . .	15,236	2,211,404	27,612	3,987,568
1867	Passenger.	12,532	1,799,408		
	Goods . .	14,846	2,146,976	27,378	3,946,384
1868	Passenger.	10,738	1,532,102		
	Goods . .	14,352	1,919,268	25,090	3,451,370
1869	Passenger.	9,828	1,392,612		
	Goods . .	13,546	1,801,618	23,374	3,194,230
1870	Passenger.	10,036	1,423,604		
	Goods . .	16,588	2,206,204	26,624	3,629,808
1871	Passenger.	9,880	1,401,920		
	Goods . .	16,302	2,168,166	26,182	3,570,086
1872	Passenger.	9,516	1,353,144		
	Goods . .	17,342	2,306,486	26,858	3,659,630
1873	Passenger.	8,996	1,285,804		
	Goods . .	18,720	2,489,760	27,716	3,775,564
1874	Passenger.	9,308	1,331,902		
	Goods . .	18,174	2,417,142	27,482	3,749,044
1875	Passenger.	9,750	1,398,150		
	Goods . .	18,278	2,430,974	28,028	3,829,124
				290,914	40,144,894

TABLE 17.—NUMBER and GROSS WEIGHT of TRAINS PASSING OVER the UP LINE of the GREAT NORTHERN RAILWAY BETWEEN BARNET and POTTERS BAR, 1865 to 1875.

Year.	Trains.	Number.	Weight.	Total of all Trains per Annum.	
				Number.	Weight.
		No.	Tons.	No.	Tons.
1865	Passenger.	10,062	1,354,864		
	Goods.	14,378	4,313,400	24,440	5,668,264
1866	Passenger.	12,532	1,686,672		
	Goods.	14,066	4,219,800	26,598	5,906,472
1867	Passenger.	12,376	1,666,236		
	Goods.	13,702	4,110,600	26,078	5,776,836
1868	Passenger.	10,894	1,466,010		
	Goods.	13,052	4,568,200	23,946	6,034,210
1869	Passenger.	10,010	1,346,202		
	Goods.	11,024	3,858,400	21,034	5,204,602
1870	Passenger.	9,412	1,266,460		
	Goods.	12,558	4,395,300	21,970	5,661,760
1871	Passenger.	9,386	1,262,808		
	Goods.	13,000	4,550,000	22,386	5,812,808
1872	Passenger.	9,724	1,308,060		
	Goods.	13,884	5,553,600	23,608	6,861,660
1873	Passenger.	10,088	1,357,616		
	Goods.	14,092	5,636,800	24,180	6,994,416
1874	Passenger.	10,530	1,416,984		
	Goods.	14,014	5,605,600	24,544	7,022,584
1875	Passenger.	11,570	1,556,932		
	Goods.	13,884	5,553,600	25,454	7,110,532
				264,238	68,054,144

Mr. R. PRICE WILLIAMS said since the Paper was written he had completed some additional experiments, at Mr. Kirkaldy's works, on the tensile and compressive strength of rails rolled from cogged and from hammered ingots, and also on steel rails which, previous to being punched, had been plunged, while hot, into water; and the results fully confirmed those previously given by the bending stress. The results of these later experiments showed that the limit of elasticity under the pulling stress was more than 12 per cent. higher in the cogged than in the hammered ingot rails, and that the limit of elasticity under thrusting stress was 5 per cent. in favour of the cogged ingot rails. Further, there were indications of greater toughness in the cogged ingot rails under the thrusting stress, the depression under weights of 100,000 lbs., and 150,000 lbs. per square inch, being 13 per cent. less.

SUMMARY of TABLE 12 (*vide* Appendix),
Messrs. Fox and Co.'s STEEL RAILS.

Pulling Stress.

—	Elastic Stress per square inch.		Ultimate Stress per square inch.		Ultimate Extension per cent. of length.	
	Rail Top.	Rail Bottom.	Rail Top.	Rail Bottom.	Rail Top.	Rail Bottom.
	lbs.	lbs.	lbs.	lbs.		
Rails made from cogged ingots	52,400	52,750	95,476	99,805	7·9	9·2
Rails made from hammered ingots	46,650	48,950	100,878	101,695	15·8	15·4
Percentage in favour of cogged ingot . .	12·33	7·76	..	..	..	..

Thrusting Stress.

—	Elastic Stress.	Percentage in favour of Cogged Ingots.	Depression at 100,000 lbs. per square inch per cent.	Depression at 150,000 lbs. per sq. inch per cent.
	lbs.			
Rails made from cogged ingots . (Rail top.)	58,000	4·97	3·4	14·0
Rails made from hammered ingots (Rail top.)	55,250		3·9	15·8

As regarded the steel rails, marked E, F, G, H on Plate 19, which before being punched had been quenched in water, the experiments showed that the limit of their elasticity under pulling stress was far higher when thus treated, the elasticity of the steel

taken from the head of these rails being, on an average, 17·61 per cent. greater. The increased toughness resulting from this particular treatment of the material was, moreover, strikingly shown by the results obtained under the thrusting stress, the limit of elasticity of the rails plunged while hot into water being 59,000 lbs. per square inch, as compared with 49,250 lbs. in the case of the untoughened rails, or about 20 per cent. in favour of the former. Again, the same favourable results were shown by the much smaller amount of the depression of the toughened rails under thrusting stress, the depression amounting only to 6·6 per cent. under a pressure of 100,000 lbs. per square inch, as compared with 9·4 per cent. in the rail which had not been so treated, showing 42·42 per cent. in favour of the material which had undergone this toughening process.

The average amount of carbon in all the steel rails of Messrs. Cammell and Co. was only ·174 per cent. for the A, B, C, and D rails, and ·179 per cent. in the case of the E, F, G, and H rails.

SUMMARY of TABLE 12—*continued* (*vide* Appendix),
Messrs. CAMMELL and Co.'s STEEL RAILS.

Pulling Stress.

—	Portions from Rail Top.				Portions from Flange.			
	Elastic Stress.		Ultimate Stress.		Elastic Stress.		Ultimate Stress.	
	lbs.	Per cent.[1]	lbs.	Per cent.[1]	lbs.	Per cent.[1]	lbs.	Per cent.[1]
Rails plunged when hot into water (G, E, F, H.)	48,075	17·61	90,750	11·72	53,250	16·08	92,555	13·78
Rails in ordinary state (A, B, C, D.)	40,875		81,225		45,875		81,342	

Thrusting Stress.

—	Elastic Stress.		Depression under 100,000 lbs. per square inch per cent.		Depression under 150,000 lbs. per square inch per cent.	
	lbs.	Per cent.[1]		Per cent.[1]		Per cent.[1]
Rails plunged when hot into water (G, E, F, H.)	59,000	19·80	6·6	42·42	20·5	21·95
Rails in ordinary state (A, B, C, D.)	49,250		9·4		25·0	

[1] In favour of cooled rails.

In the course of the discussion on his former Paper on Rolling Stock, exception had been taken to the average rate of depreciation assumed in the case of locomotive engines, which increased, according to his view, as the square of the time; his contention being, that while the rate of depreciation of some of the longest lived parts of the structure was tolerably uniform, many other parts were exposed to constant wear, where the rate of depreciation must necessarily be much more rapid, being probably as the cube of the time; but that the average rate of depreciation of all the parts would be a mean between these two extreme cases, a condition fulfilled by the ordinary parabolic curve. The means of practically testing the rate of depreciation of iron rails had, since then, fortunately presented itself, and he had been enabled, through the kindness of Mr. Johnson, M. Inst. C.E., Chief Engineer of the Great Northern Railway Company, to exhibit diagrams, Plate 20, showing the actual failures of guaranteed rails, and extending over periods of seven years. It would be observed, that the outline, showing the rate of failure of the rails of the 4,000 tons contract, Fig. 1, almost exactly coincided with his curve of average depreciation, which increased as the square of the time. The figures No. 2 and 3 showed the rates of failure in the other two contracts for guaranteed rails of 1,600 tons and 1,400 tons respectively. The curves in these cases indicated a depreciation increasing in a somewhat higher ratio than that of the square of the time. This afforded a strong confirmation of his view, that in all structures composed of different parts, and subject to wear, the curve of depreciation must necessarily be of the character described. Following out that idea, he exhibited a diagram (Plate 20), showing the value of 1 mile of permanent way, at successive periods, assuming the depreciation to increase as the square of the time, and the life of steel rails to be forty-two years. In this diagram the serrated outline showed the net value of the permanent way, before and after each renewal of the different parts. The curved line of average depreciation gave an exact average of the irregular serrated outline, and its mean ordinate occurred at about twenty years, or, in exact figures, at ·577 of the longest life—at which period the permanent way would have attained its average value, viz., two-thirds of the first net cost, to which, of course, for purposes of valuation, would have to be added the scrap value of the materials. It consequently followed that the normal depreciation in 1 mile of permanent way was one-third of its first net cost.

With regard to the tests of the fish-plates, it would be seen that the bearings were 5 feet apart, and that the results were relative.

Mr. Kirkaldy had declined to test the rails with 2-feet bearings, thinking, and he thought correctly, that with bearings 2 feet apart it was impossible to get any useful result as to deflection or set: nor was it fair to consider rigid supports 2 feet apart as at all comparable with sleepers 2 feet apart. He was glad of the opportunity of expressing his obligations to Mr. Kirkaldy for the great assistance afforded him, apart from business considerations, throughout this inquiry.

Mr. May said a cogged ingot was, in truth, simply the reduction of an ingot to the size of the bloom—say from 12 inches to 6½ inches square. Whether done with a hammer or by rolls it was still cogging. The only difference between rolling or hammering an ingot down to the bloom was that, in hammering, the result was an ingot with a rounded end, on account of the percussive force driving out the soft metal towards the end; and in the other case a bird's-mouth ingot, by drawing the metal over; the tensile strength and wearing properties were the same, whether the reduction was effected by hammering or by rolling. He did not understand what was meant by toughening by plunging into water. Steel with a sufficient amount of carbon was hardened by plunging into water; with less carbon it was made more resistant, but not tougher. As to punching and drilling, there was no difference in the results, except that in the punched rail there was sometimes a minute crack at the end which came out in the wear. Punching or drilling did not affect the actual strength of the rail.

Mr. W. B. Lewis felt under great obligation to Mr. Price Williams for the mass of information he had collected, to which it seemed hopeless to attempt to add anything. But on one or two points he thought there was not material enough to form an accurate opinion. He had studied the table of analyses with great interest, but without much satisfaction. With reference to carbon, which was usually regarded as most important in the composition of steel, it was true that a rail with a minimum of carbon showed the best result. With rails 17 and 18 at the Maiden Lane tunnel the minimum of carbon showed the better result, but with the next two rails from Copenhagen tunnel, the circumstances being the same, the maximum of carbon gave the better result. Looking at the table, the only thing that seemed evident was, that the rail with the smallest amount of phosphorus was the best, and there seemed to be a pretty regular progression. He believed some engineers had lately inserted in their specifications the chemical test for steel and iron rails. With regard to the question of punch-

ing he felt compelled to differ from Mr. May. His own experience was that the effect of punching a steel rail was to weaken it. The material was brittle, and if in punching any little fractures were produced, however minute, even if hardly discoverable by the microscope, they were liable to increase; and with the jar and concussion to which rails were subjected mischief might be done. But drilling he had found to be a very serious matter. In the case of a large order for rails from the Barrow Company, drilling oval holes had been insisted upon; and the Company put up several machines made by Messrs. Sharp, Stewart, and Co., for the purpose; but all sorts of practical difficulties arose. The machines were so arranged that two rails were brought together and two holes in each rail were drilled at the same time, and it sometimes took eighteen minutes to get through the four holes. The order being for 6,000 tons, they were alarmed at the idea of spending so much time over the operation of drilling. It was also found that the skin of the rail differed so greatly, that where one tool would enter freely the next would be turned, and the tools would not travel at the same pace. All those difficulties were, however, surmounted by adopting the plan which Mr. Williams had described, viz., punching a small hole first, through which a cutting tool could be put, taking a centre on the other side, and then cutting an oval hole, or rather an elongated hole with two round ends. The rule adopted was that every hole should have at least $\frac{1}{8}$ inch cut away by the cutting tool. Again, with regard to cogging and hammering, he could not help thinking that sufficient information had not been obtained. The Author had supplemented the Paper by additional remarks on this subject, but in the Paper itself there was not enough to justify the conclusion, that the one plan was better than the other. Engineers in charge of the maintenance of way state that they had no occasion to complain of the fish-plates, and that they saw no reason for incurring the expense of deeper ones. It appeared that the fish-plate in Fig. 22 broke the rail. It was manifest that there was more iron in it than was needed. The joint was said to be 66 per cent. of the strength of the solid rail. By adopting the customary plan of reducing the bearings to 2 feet at the joint instead of 3 feet elsewhere, there would be a gain to nearly the extent of the loss thus indicated, and the joint would be as strong as the rest of the rail. The result seemed to point to there being too much material in the fish-plate. Looking at the section adopted on the Metropolitan railway, it appeared that neither the fish-plate nor the rail gave way, but the bolt. That seemed to betray a bad-fitting

fish-plate. He did not think that the ultimate strength of the joint was that which it was needful to ascertain, but the stiffness; so that one rail should not deflect before the other. His opinion had always been, that a fish-plate should be so made that no sheer could come on the bolts, but that their work should be limited to holding the two cheeks together. In the case in point it appeared that the bolt was doing work that ought not to be required of it. If the shoulder of the plate had been made to fit under the rail, either the rail or the plate must have gone before the bolt, or the thread must have stripped. He hoped to hear whether the plate in common use, when well made and fitted, was found in practice to be unequal to its work.

Mr. LANGLEY said, in 1874 he laid down some permanent way near Stepney on the Blackwall branch of the Great Eastern railway, where there were upwards of three hundred trains a day passing over a single line. The weight of each train was, on an average, about 150 tons, making a total of about 45,000 tons daily over one line of rails. The permanent way on this length was composed of both steel and iron rails (from nearly all the principal manufacturers in England), weighing 80 lbs. to the yard, and keyed in cast-iron chairs resting on rectangular sleepers. The steel and iron were purposely laid close together so as to be under precisely similar conditions of wear and tear. The greater number of the wrought-iron rails had to be turned in one year and three-quarters, during which period they had worn down about $\frac{1}{8}$ inch; but they had not to be turned on account of this wear, but because they gave way in places either by bulging or by splitting. The steel rails had worn about $\frac{1}{16}$ inch in one year and three-quarters, after about 27 million tons had passed over them; which was rather in excess of the figures given by Mr. Williams. The fact of the wrought-iron rails wearing away twice as much as the steel was not an indication of the true value of the two metals; because the steel rails after wearing down $\frac{1}{16}$ inch were still available, and would continue to be so until nearly the whole of the head was worn off, the wearing down being regular and uniform. The iron rails, on the other hand, were crushed in places and no longer fit to remain in the road. He had found that the old rails were far more durable than the new ones now supplied by manufacturers. The latter were like a bundle of fagots not tied properly together, and always gave way either by bulging or by splitting; in fact, their life was most uncertain, while the old rails wore down more like steel rails. He had invariably put the sleepers about 2 feet apart at the joints, increasing the distance to about 3 feet in the centre

of the rail. This being done, and with the ordinary fish-plate properly screwed up, the joints could not be felt, and a continuous elastic line of rails was obtained.

In February 1873, at the Nine Elms goods-yard on the London and South-Western railway, he had laid a steel rail on one side and an iron rail on the other side of the shunting road where there was most traffic, an average of nearly four hundred engines and trains passing over this line in the twenty-four hours. The steel rail at the present time was in good condition, a layer of $\frac{3}{16}$ inch being worn off; while during the same period, over three years, on the opposite side the iron rail had been renewed three times, the renewal taking place after each rail had been turned, and both heads so worn that the rail was unfit to remain.

It was curious to notice the difference of opinion amongst Engineers as to the best form of rail section. On the Continent and in America, Engineers had almost invariably used the flat-footed rail; and he noticed last week that, on some of the western lines in France, rails keyed in chairs were being replaced by flat-footed rails. On the Metropolitan line, on the contrary, the flat-footed rail was being taken up and the rail in chairs substituted. The only recommendation the flat-footed rail had appeared to be its smaller cost in the first instance. It was more difficult to maintain and did not make so elastic a road. The cost per ton for rolling a flat-footed rail was more than that of a double or bull-headed rail, and the chair rail was taken out and replaced much quicker than a flat-footed one.

He had always found that, with heavy traffic, the second head of a wrought-iron double-headed rail, when turned, had lasted as long as the first. This was the case with all the rails laid down at Stepney. There was, however, no advantage in making a double-headed steel rail. Almost all of the relaying of the Great Eastern railway was being done with steel bull-headed rails.

Mr. Cowper observed that the question of the amount of carbon in steel had been thoroughly investigated, and a great amount of evidence on the subject would be found in the Transactions of the Iron and Steel Institute. He wished to draw attention to the fact, that inasmuch as there had been thousands of tons of steel rails made in early times by the Bessemer process, without sufficient manganese to give the best results, it was necessary to be very careful in comparing the results of the wear of steel rails having different proportions of carbon in them; it was especially so when the rails contained other impurities, such as sulphur, phosphorus, silicon, &c., as manganese was a great corrective of

their evil influences, and good ingots, that would bear hammering, cogging, and rolling, could be made when sufficient manganese was used, in cases where they could not be without. He had seen bad crop ends, 3 feet long, when sufficient manganese was not used, and again the circumstances totally changed and good ends made with a more liberal use of manganese. It was not, however, altogether a question of the amount of manganese in the finished steel, and he believed that in the Bessemer process some of the manganese used was not found in the finished steel, but did excellent service in the converter, by uniting with the silica and forming a slag with it, thus purging the steel of silica, whilst some portion of the manganese also effected good by absorbing the oxygen from "overblown" particles of iron, which would otherwise have set up ebullition by forming carbonic oxide with a portion of the carbon, and thus causing honeycomb. Another point that could not be too carefully guarded against was, that of comparing rails that had not been treated in precisely the same manner; thus one might be thoroughly annealed, and even kept warm for a time in the midst of a large heap of red-hot rails, and another, precisely like it, might be chilled to such an extent as to be rendered considerably harder. It was, however, a fact that good steel, with 0·1 or 0·2 per cent. of carbon, might be heated and quenched with impunity; but with 0·3 per cent. of carbon the steel might harden or not, he believed, according to whether it contained other substances or not. Manganese was important in steel having a low amount of carbon, as well as to give toughness to steel having a higher percentage of carbon together with impurities. There was now no difficulty in making a regular uniform quality of steel plate with a very low portion of carbon in it, and thousands of such plates, having greater ductility than iron, had been made without a failure. He exhibited a piece of rail of a section designed by the late Mr. John Braithwaite for the Colchester branch of the old Eastern Counties line, which was laid in 1843 and taken up in 1868. It was a Low Moor rail, and showed no spreading or lamination; a layer of $\frac{5}{16}$ inch had worn fairly away, and the rail was of as good a shape as ever. The section was adapted for giving a suitable support to the wearing surface.

Mr. Riley said, as he had analysed rails for Mr. Price Williams, and had not only examined them chemically, but, as far as he could, mechanically, he might be permitted to make a few remarks on the condition of the rail and on the carbon question. Engineers might be somewhat perplexed by the statement that the results

given confirmed the remark made by Mr. J. T. Smith, M. Inst. C.E., that greater hardness of material did not conduce to the longevity of steel rails. He did not quite agree with Mr. Price Williams on that subject. The question was, did the percentage of carbon necessarily indicate hardness of rail? He thought not. Mr. Menelaus, M. Inst. C.E., than whom, perhaps, there was no better authority in the country, had said not long since that it was due to the engineers that the steel rails now made did not stand as they formerly did. He attributed it to the falling-weight test that engineers insisted upon, which required the manufacturer to put less carbon into the rail, and so to make a softer and tougher material. It was perplexing to find two eminent authorities disagreeing on such a point; and the question was how the two statements could be reconciled. Did it necessarily follow that because a rail contained a certain amount of carbon it had a certain amount of hardness? He believed not. The rails from the Great Northern line had been sent to him with the remarks of the engineer, and they were carefully analysed by himself, his experiments being verified by the colour test applied independently by another person. It would be seen from the figures that the percentage of carbon did not necessarily indicate the hardness of the rail. Taking the rails shown in Table 7 it would be seen that the analyses were exactly the same; for although it might be said that there was a difference of 0·02 per cent. in carbon, he could say, as a practical chemist, that it was impossible to come nearer than about 0·02 per cent. One of these rails was hard and the other soft. They were quite different mechanically; but chemically they were the same. He was inclined to think that it was not so much the percentage of carbon as the way in which the rails had been cooled that should be taken into consideration; 0·40 per cent. of carbon would give a very hard rail. He had had pieces of rail sent to him containing that amount of carbon, and they could only with difficulty be touched with a tool; and, on the other hand, he had had a steel bolt containing 0·8 per cent. of carbon which he could drill easily. If a rail were made with from 0·2 to 0·3 per cent. of carbon, and cooled when red-hot in water, a tough and moderately hard material would be obtained. The rails that had been referred to as having been put into cold water and punched contained rather under 0·2 per cent. of carbon. Mr. Smith's test in reference to punching rails appeared to him to be a most valuable one. If the rails were hardened as he suggested, and contained 0·35 or 0·4 per cent. of carbon, he believed the material would break the tool

applied to it; but he intended to make some experiments on that subject. One of the most interesting points in the analyses was, that in some of the rails there was a considerable amount of phosphorus, in one case nearly 0·25 per cent., and in some cases 0·2 per cent. If it could be shown that fair steel rails could be made with that amount of phosphorus it would be of great practical use. His impression was that the amount of phosphorus at present set down for rails was rather too low. He admitted the tendency of manganese to harden the rail, but he could not quite agree with the conclusions to which Mr. Cowper had arrived. There was one rail on the Metropolitan line having 0·64 per cent. of silicon, and the result of the analysis led him to regard it as a most dangerous rail. With reference to colour tests he might mention that some of Siemens's metal was said to contain 0·2 per cent. of carbon according to the colour test; but, on carefully examining it, he found it only contained 0·05 per cent. In experimenting with the colour test he had found it impossible to determine the quantity of carbon in the very low steels. He had no desire, however, to throw any disparagement upon the colour test, which he thought a valuable and practical one. His own experiments had been tested in that way, and the results were marvellously near. At the same time he found that errors were occasionally made, because two persons did not always see the same colour, or see the same thing in the same way, or they might have a different standard.

Mr. Tomlinson wished to correct the statement in the Paper that Plate 17 indicated the "renewals of permanent way on the Metropolitan railway since the opening of the line." It only gave the result of the three years from January 1873 to December 1875. Many parts of the line approaching the stations had previously been relaid by his predecessor. Plates 12, 13, and 14 exhibited such varying results that he must suppose the circumstances were different, and therefore the figures could only be useful to those who knew the exact conditions of the lines. The table exhibiting the life of steel rails at forty-two years astonished him, as on no main line of railway could such a life be expected, judging from his own experience. On portions of the Metropolitan railway where no breaks were used, experience indicated a life of only about eight years, or a total of 100,000,000 tons passing over a pair of rails. The line had been originally laid with iron rails, which, so far as he could ascertain, had an uncertain life of from a few weeks to about one year. Portions of the line had also been laid in its earlier days with Dodd's case-hardened rails,

and these too had given way speedily. Then small steel rails, weighing about 65 lbs. per yard, 3½ inches high, of the Vignoles section, had been laid here and there, some few of which were still in the branch-roads. In 1866 and 1867 the whole line had been laid with steel rails, weighing 84 lbs. per yard, of the Vignoles section, 4½ inches high, with a base of 6 inches, and this form was still in the road from King's Cross to Bishop's Road. In 1866 the line was opened from Farringdon Street to Moorgate Street, and laid with rails of the same section, but they had all now disappeared.

In arriving at the fair life of a rail, circumstances should be taken into account besides the rail; and in his opinion the sleepers and ballast had a great deal to do with the results. In the diagrams showing the wear of the Metropolitan rails (Plate 18) great difference of wear was shown, although the trains were practically the same. The rails Nos. 1 and 2 were laid on sleepers 10 inches by 5 inches, notched for the cant of the rail, and therefore only 4½ inches thick; whereas the rails Nos. 3 and 4 were carried on sleepers 12 inches by 6 inches, and baulks of 13 inches by 6½ inches. Rail No. 5, on a line worked as a single line, had been laid on sleepers 10 inches by 5 inches, cut like Nos. 1 and 2. Rails Nos. 6 and 6*a* were on baulks 13 inches by 6½ inches; and he thought the difference in the wear would prove the advantage of a good substructure. Rail No. 6*a* was in a place subject to dropping water, and this was probably the reason for its excessive wear compared with that of its neighbour. The small scantling of the sleepers was, he thought, the cause of the short life of the rails, and accounted for the rails laid in 1866 between Farringdon Street and Moorgate Street having all disappeared. They were laid on sleepers 10 inches by 5 inches. This road gave so much trouble to keep up, that he began to relay it with the large bull-headed section of rail, weighing 86 lbs. to the yard, at the newest end of the road.

In estimating the fair wear of rails, the character of the work should be considered quite as much as the number of tons passing over the line. Speed was an element of great importance. Rail No. 6 had suffered more than rails Nos. 3 and 4, although supported on the same class of sleepers, as the trains ran at fully 30 per cent. higher speed in the former instance.

He was surprised at the wide differences in the quantity of carbon contained in the rails referred to in the diagrams, and he was still more puzzled at the results; as in some cases excess of carbon seemed advantageous, and in other cases the reverse.

He had come to the conclusion, from many examinations, that the fair average life of a steel rail was represented by a wear of $\frac{1}{16}$ inch for each 5,000,000 tons passed over it. The table for the Metropolitan railway gave nearly this. The Great Northern, Table 6, eliminating No. 24 rail (which had most likely been changed), showed a life of 4,376,571 tons for each $\frac{1}{16}$ inch wear of the table. Nearly the same result was obtained with the Crewe rail, C, Table 5, although perhaps it could hardly be taken as a guide, as all the rails drawn had been worn out, so far as the main line was concerned, long before they were taken up, owing to the want of more rigid fishing.

Railway engineers had to think not only of the wear, but of the safety of a rail. He had known rails break in two on being dropped from a truck to the ground; and it certainly would not be safe to put such rails on any main line. Fishing the joints carefully was highly conducive to the longevity of the rails, and this, he thought, had not been hitherto sufficiently considered, nor the most suitable form of rail for fishing. He had tried to design rails for the renewals, so that the fish-plates should rest on angles instead of curves. The fish-plates were of a deep form which came below the rails: they weighed 48 lbs. a pair, and were 20 inches long. When tested with 5-feet bearings by Mr. Kirkaldy they showed about 67 per cent. of the strength of the rail. He laid the sleepers 2 feet 8 inches apart from centre to centre, and put nine sleepers of 12 inches by 6 inches to a rail 24 feet long. The equal spacing enabled the long fish-plate to be inserted. The original road had been laid with fishes 16 inches long, but as the depth between the head and flange was small the joints soon gave way, and the rails showed signs of wear towards the end, or where the wheels left one rail and reached the next. This, in a few months, extended over a length of about 1 foot, the ends of the rails being worn down nearly $\frac{1}{8}$ inch. Recently he had a large number of broken and cracked rails, resulting from their having been punched, which had all given way along the fish-holes, showing an incipient fracture, that had extended. He did not think that punching a small hole and subsequent drilling would be so trustworthy as complete drilling; it was impossible to punch a hole of less diameter than the thickness of the web of the rail, and if the web was $\frac{3}{4}$ inch thick the hole punched must be $\frac{3}{4}$ inch in diameter, so that enough metal would not be left for the removal by drilling of the portion damaged by the punch.

Mr. Bramwell mentioned an old project of his for doing away

with crop ends, and with the risk of having bad ends to the rails, arising from a desire to minimise cropping as much as possible. It had been stated by Mr. May how, when cogging was done by rolls instead of by hammering, there was a concave end to the bloom, and that when the rail was finished this concavity became rolled out into an imperceptible crack, which, if a large crop end were not cut off, was left in the rail and injured it, manifesting itself in work. Mr. Bramwell's proposal, which he hoped some day to see carried into effect, was to manufacture rails as weldless and endless tires were manufactured; that was to say, by rolling each rail in a hoop form, then cutting it open, and rolling it out straight. In such a mode of manufacture there would be no crop end and no unsound part, because a hoop, having neither beginning nor end, would be uniform in quality throughout.

Dr. Siemens said there seemed to be a great divergence of opinion with regard to the quality of steel composed of different percentages of carbon. Mr. Riley, who had given considerable attention to these questions, no doubt could have supplemented the information by further chemical details, which perhaps he did not like to do because there was at present doubts as to the specific effect produced by other materials, such as phosphorus, sulphur, silicon, &c. Dr. Siemens might perhaps be able to supply some data regarding steels in which the proportions of different materials reached their limits on the one side or on the other. It had been said that steel containing a considerable percentage of carbon, 0·4 per cent., was very soft. That might be partly owing to the tempering, for if the steel had been slowly cooled it would be soft, but it might also be owing to the manner in which the carbon was combined. Carbon was not always chemically combined even in steel. In the process of mixing spiegeleisen with the blown metal at the last moment in the Bessemer process there was hardly time to form a chemical combination, and hence metal might be produced which contained a considerable proportion of carbon, and yet was essentially soft metal because the carbon was not chemically combined. He had observed, in boring a large cylinder of steel cast from metal of that description, that at one point the boring tool went deeply into the metal, and at another point there was a resistance as though the metal were hard. In such a case no effect of temperature, of sudden cooling, was involved, because of the particular form of the metal. The phenomena showed clearly that steel was not always homogeneous unless special care had been used to make the mixture

perfect. Mr. Cowper had attributed to manganese the quality of making the metal tough, whereas carbon made it hard. That was not universally the case. In the case of steel containing as much as 0·4 or 0·5 per cent. of carbon, little manganese was desirable or necessary to make the metal forge properly; but in the case of very soft metal, and metal containing phosphorus, the manganese was an essential condition. For instance, 0·2 per cent. of phosphorus, which was about the maximum amount admissible, necessitated about 0·4 per cent. of manganese to make the metal at all workable and to prevent its extreme brittleness when hard; but in metal containing hardly any carbon, less than 0·1 per cent., manganese was of the utmost importance, and without it the metal could not be got to work or stand against the grinding axle. The manganese seemed to bind the particles of metal together, and to make it more homogeneous. Mr. Riley had mentioned the difficulty of determining such a slight amount of carbon by the ordinary colour test. No doubt the difficulty was great, but Mr. Willis, of the Landore Works, had introduced a test for determining a very slight proportion of carbon, sufficiently accurate for all practical purposes, by dissolving the metal in nitric acid and observing the effect of colour on the solution. The nitric acid did not act upon the carbon, and it produced a brown tinge of sufficient intensity to be distinctly observable, even though the proportion of carbon should be considerably below 0·1 per cent. This test would enable manufacturers to produce steel of extreme mildness, such as was now used largely for engineering purposes. It was impossible to estimate so slight a difference in carbon as 0·05 or 0·1 per cent. by any mechanical test; but by a ready chemical test of that kind the manufacturer was enabled to bring the metal down to an exact point considerably below 0·1 per cent. No doubt these questions were at present only partially understood, and much work was still required in order to arrive at certain conclusions regarding the conditions necessary to produce steels of definite qualities. If steel was produced from pure iron, such as was found in Sweden, a metal could be made containing hardly any manganese, and only a trace of carbon, and no appreciable percentage of phosphorus or silicon; and metal of that description, which was as nearly as possible of pure iron, was perhaps the toughest that could be made, exceeding in toughness copper or even silver. A further advantage of such metal was that it was less liable to rust. Experiments lately made in France showed a percentage of rust, as compared with wrought and cast iron, in the proportion of 0·4 to 1·4, being much in favour of a pure metal such as a very

mild steel—a quality of great value for shipbuilding and purposes of that kind.

Mr. Brunlees had on a former occasion expressed the opinion that the fish-joints of railways were the most unmechanical things connected with them, and he had no hesitation in repeating the statement. He thought there was room for improvement in fish-joints, and he was glad to find that the attention of Mr. Tomlinson was directed to the subject. He considered the best rail was that which had plenty of metal in the head and a small proportion in the foot, forming what he would call a girder section. In that case the metal was properly distributed, and both the tension and the wearing part were where they ought to be. If such a rail was more generally adopted, better results would be obtained. He knew of no form of permanent way better or stronger than that of smaller dimensions, which he had used in 1852 and ever since, both at home and abroad, with excellent results.

Mr. Riley said it was certainly an omission on his part not to have mentioned the different conditions in which the carbon existed in steel rails; but, having so many analyses to make, he had not been able to complete the tests, but he intended to do so.

Mr. Sandberg observed, through the Secretary, that few, if any, foreign governments or departments of public works could show information of equal value to the statistics collected by the Author, and illustrated in this and other Papers on the railways of Great Britain. The Paper entered into the metallurgy of iron and steel as applied to railway bars, a subject which he had made his speciality, and he would therefore offer some remarks, based upon his practice as inspector of rails for seventeen years for the Swedish government and other railways. The Paper furnished ample proof of the superiority of steel to iron for railways, unless the traffic was very light. The price of steel rails had been reduced during the last ten years from double that of iron to only 25 per cent. more than the price of iron, but he feared at the expense of their quality. Since it had been attempted to produce steel rails of inferior and cheaper raw material, engineers should be on the look-out for their safety more than for their durability, as they and not the makers were answerable for the consequences. Owing to the great competition now existing in a slack state of trade, the tendency was to cheapen the make and to "avoid loss" by manufacturing rails regardless of their safety, which in his opinion was of greater importance than durability. With this view he would

warn railway authorities, particularly those who, like his friends, had to contend against a cold climate, not to sacrifice the safety, tenacity, stretch, or extensibility of the steel for greater durability through hardness; all the more so if this hardness was produced by phosphorus or silicon, which also made it brittle, instead of by carbon and manganese. It had been stated that an amount of 0·2 per cent. of phosphorus was the maximum admissible, but only half that could be safely tolerated for a cold climate, admitting, however, that the smaller the amount of carbon the greater could be the amount of phosphorus in the steel without brittleness. Hard steel could be rolled better than soft. There was some difficulty in determining the amount of carbon in steel by the Eggertz coloration test when the amount was small, but Professor Eggertz had lately told him that sufficient accuracy for all practical purposes could be obtained if the solution was made at a temperature of 176° Fahr., and also if no light was admitted during the process, for which purpose a special apparatus had been constructed.[1] He had supplied standard steel, obtained direct from Professor Eggertz, to many steel-makers, in order to facilitate the testing of every cast, but he was sorry to find that there were still many steel-works without either a laboratory or a chemist, which he thought highly necessary in these experimental times. In his opinion the cogging was a more severe test for the steel, as generally it gave more wasters than the hammer, which latter would only work steel somewhat red-short into clean rails. He thought that drilling was safer than punching rails; still, if the steel was soft and the hole not too near the end, so as to leave, say, a depth of 1½ inch of solid metal in the web of the rail, punching was safe enough. Another means to obviate the breakage of iron or steel rails in the punch-holes was to prevent the blow against the bolt on the upper part of the hole every time the train passed over the joint by making it as stiff as the solid rail; the ordinary weak joint was no doubt the cause of that mischief. He had tried many experiments both by dead weight and blow on the strength of rail joints,[2] and could confirm Mr. Brunlees' opinion as to the inferiority of the ordinary rail joint. For existing lines, with the joint sleepers as close as practicable, angle fish-plates having 67 per cent. of the stiffness of the solid rail would probably be the best. Such were now laid on the Swedish State railways without base-plates, extending vertically to the flange of the rail and horizontally to

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 411.

[2] *Vide* "Engineering," 25 November, 1875.

allow four holes for spikes to be punched through the flange so as to nail them both inside and outside to the sleeper; thus the road would be better kept both horizontally and vertically than by the ordinary fish-joint. For lines in construction the best joint, in his opinion, would be a fish-plate of such depth as to afford the same stiffness and elasticity to the rail joint as the solid rail with the same distance of joints as of sleepers, say 3 feet from centre to centre. With such a fish-joint applied to a rail-section of small fishing angles, say from 11° to 15°, so as to throw less work upon the bolt than with the pear-formed rail-section of 30°, neither breaking of bolt-holes in the rail, nor sinking of the joint, with too early failure of the rail ends and rolling-stock, would be risked, and this would, in his opinion, materially reduce the maintenance and renewals, and increase the money life of the permanent way.

Mr. R. H. Tweddell remarked, through the Secretary, that a large portion of the cost of maintenance and renewals of the permanent way of railways had been shown to be due to the fact that the crossings, as now made, formed their weakest part. He believed that the continuous crossing, designed by the Author some years ago, in order to remedy this defect, effectually preserved what might be termed the 'continuity of elasticity' of the line, obviating the objectionable anvil-like action of cast-steel crossings, and the looseness and want of continuity of the ordinary forms; but the cost of manufacture had hitherto prevented its being offered at a price sufficiently low to insure its general adoption. Again, in the previous form of these continuous crossings, a special or solid section of rail had to be used, to insure sufficient material in the web after the groove was slotted out, and involving special machining at each end to enable the connection to be made to the next rail by the usual fish-plate. Hence it occurred to Mr. Price Williams that hydraulic pressure might be adopted to make these crossings, and Mr. Tweddell had designed a machine for this purpose, and had successfully applied it to some Landore Siemens' steel rails of the 80 lbs. double-headed section, which were passed through a special set of dies and stamped into the finished form. The question was simply one of forming the dies so that portions of the rail were forced to flow while hot into spaces prepared for them: thus the material was moved from where it was not required, and utilised by being placed where it was specially wanted to strengthen the rail, so that the crossing became uniform and equally elastic with the rest of the permanent way. A saving of 50 per cent. was effected in the first place in the material of the crossing, inasmuch as the weight of solid rail, as

compared with the ordinary rail, now required was as 120 to 80; and finally all machine-work was dispensed with, as the squeezing was done at one blow. In Mr. Tweddell's opinion, it was difficult to place any limit to this illustration of the practical application of M. Tresca's researches on the flow of solids; and he believed by this process wrought-iron or steel railway chairs might be made almost as cheap as cast-iron ones. Should this prove to be the case, further economy would be effected in the maintenance of permanent way.

May 30, 1876.

JAMES ABERNETHY, Vice-President, in the Chair.

THE following Candidates were balloted for and duly elected:—GEORGE FREDERICK ADAMS, GEORGE BAIRD, SAMUEL BAILEY COXON, EDWARD EASTON, and WILLIAM SULLIVAN HARINGTON, as Members; JAMES BUTLER, FRANK STUART COURTNEY, Stud. Inst. C.E., HENRY DANGERFIELD, ARTHUR GEORGE FENN, HENRY GOOCH, EDWARD FYFE GRIFFITH GRIFFITH, Stud. Inst. C.E., HENRY TYLSTON HODGSON, WILLIAM LANGDON, AUGUSTUS VAN ZANDT MACDONALD, WILLIAM PATTERSON ORCHARD, B.E., Stud. Inst. C.E., the Hon. RICHARD CLERE PARSONS, B.A., Stud. Inst. C.E., WEBSTER PAULSON, Colonel FREDERICK WESTON PEILE, R.E., EDMUND WALTER PLUNKETT, SIDNEY PRESTON, Stud. Inst. C.E., JOHN WILLIAM RANDELL, Stud. Inst. C.E., JOHN SHAW, ALEXANDER SMITH, ARTHUR TOULMIN SMITH, Stud. Inst. C.E., JOHN PHILIP SPENCER, SYDNEY STENT, Major EDWARD HARDING STEWARD, R.E., ALFRED THORNE, ROBERT CHARLES TURNER, CHARLES HENRY ALEXANDER TWIDALE, and CLEMENT HEATHERLY WILMOT, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred JAMES MCNAIR HARKNESS, PHILIP CAUSTON LOCKWOOD, RICHARD PROCTOR-SIMS, and JAMES NELSON SHOOLBRED, B.A., from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—ROBERT SINCLAIR CAMPBELL, PATRICK EDWARD DOVE, FRANCIS JOSEPH EDE, THOMAS LINDSAY GALLOWAY, M.A., ROBERT GRINDLE, ROBERT COLLETT MAWSON, AMYAS MORSE, CHARLES ANTHONY STOESS, ALGERNON ROBERT SUTHERLAND, and BENJAMIN HOWORTH THWAITE.

The discussion upon the Paper, No. 1,479, on "The Permanent Way of Railways," by Mr. R. PRICE WILLIAMS, occupied the whole evening.

June 1, 1876.

The Session was concluded by a Conversazione, which was given by the President and Mrs. Stephenson at the South Kensington Museum, by permission of the Lords of the Committee of Council on Education. In addition to the members of all classes of the Institution invitations were sent to and were accepted by a numerous circle of distinguished men of science and others; and in every case the card of invitation admitted a lady.

Sect. II.—OTHER SELECTED PAPERS.

No. 1,334.—"Slate Quarrying in the Festiniog District, North Wales." By Alfred Andrew Langley, M. Inst. C.E., and Charles James Bellamy.

There are about twenty quarries at the present time worked, or about to be opened in the district referred to in this Paper, all of which lie within a radius of 2 miles from the terminus of the Festiniog and Portmadoc narrow-guage railway.

The workable part of the slate formation seldom exceeds 200 feet in thickness; the dip of the strata being to the magnetic north, at an angle of about 30°. The slate is intersected by veins of greenstone, locally called 'hards,' lying conformably with it, and dividing it generally into four distinct veins, known as the 'Flag,' 'Upper,' 'Old,' and 'South' veins respectively.

The volcanic veins vary from 1 foot to 40 feet thick, sometimes thinning out altogether. They are very hard, being composed of spar, flint, and other silicious compounds, sometimes even of pure flint. The three lower slate beds, viz., the 'Upper,' 'Old,' and 'South' beds, are from 1 foot to 150 feet thick; but the 'Flag' or top rock is often of a greater thickness. The slate from this bed is not of a close durable texture, unless at a great depth; consequently the slates made from it are of an inferior quality, being for the most part 'second slates,' with an uneven surface. Large slabs are made from the slate in this bed, but they require planing. The 'Upper' bed, called also the 'Back Vein,' is of a fine quality, but usually contains a number of thin light-coloured beds, called sand veins, harder than the slate itself, and of a gritty nature. They run parallel to the slate beds, crossing the plane of cleavage obliquely, the cleavage being not quite so true on this account, which detracts from the appearance of the slates, and renders them less saleable than they otherwise would be. The 'Old Vein,' known by many as the 'Old Festiniog Vein,' furnishes the finest quality of slates, from which some of the best quarries produce most of their 'yield' or 'make.' This bed almost invariably contains the double clay slant, or 9-inch stone. This consists of two beds of soft white clay, each about $\frac{1}{8}$ inch thick, and between

them a bed of slate 9 inches thick, the regularity of which is remarkable.

These clay slants form a reliable guide to the quarrymen, extending, in almost a true plane, over considerable areas, and immediately under them is the superior slate above mentioned.

Over the 9-inch stone there is generally a bed of hard unworkable rock, from 2 to 8 feet thick, which is sometimes made to form the roof in underground workings. In the lowest, called the 'South Vein,' the slate is solid, and as durable as that in the 'Old Vein'; but the surface is rougher, and the slate does not split so well. It can generally be determined, from the appearance of the slates when manufactured, from which of the four beds above described they have been obtained; the beds maintaining their characteristic features very uniformly. The slates from each of the four beds in the Festiniog strata are of a bluish colour, and can thus be easily distinguished from the Bangor slates, which are for the most part red, and for this reason often preferred to the Festiniog slates. The phenomenon of cleavage, though occurring in other geological deposits, exists in a more marked degree in slate than in any other rock; hence the term usually applied to it, viz., 'slaty cleavage.' It is technically known as the 'split' of the slate, being the direction in which the slate is capable of being split up into indefinitely thin laminæ.

The cleavage planes are entirely distinct from the stratification, and often make a considerable angle with it. The plane of the cleavage in this district inclines in the same direction as the dip of the strata; consequently the strike of the cleavage and of the stratification are parallel to each other. As the dip of the strata is to the magnetic north, at an angle of about 30°, and the planes of cleavage incline downwards in the same direction at an angle of about 45°, the cleavage planes make an angle of 15° with the bedding of the strata.

There is also a secondary cleavage, in the direction of which the slate is easily, but not so readily, broken, called the 'pillaring' of the slate. Here, the line of the 'pillaring' makes an angle of about 15° with the magnetic north (Plate 21, Fig. 2). The plane of the pillaring is in some cases vertical, and in others deviates from it by as great an angle as 90°, and the walls of the chambers are made to coincide with it.

The above description of the lay of the beds is applicable to most of the large quarries, and is a fair general account of the district, but there are isolated cases where, owing to local disturbances of the strata, it might require modification.

The slates are most easily split immediately after the rock is quarried; the 'Flag Vein' in particular soon loses its cleavage if allowed to dry, and becomes unfit for slate manufacture, for which reason the workmen often cover a block with wet peat to retain the cleavage until they can work it into slates.

The slate from the lower beds, which is of a closer texture, retains its cleavage much better, and is occasionally sent to London in block. Frost also acts injuriously on the cleavage, and the rock, even before it is quarried, is sometimes injured for several feet in depth if in an exposed situation. For this reason it is desirable, in severe weather, to cover the workable slate with rubble. Near the surface cracks often occur in the slate, called 'water splits'; they are generally of a reddish colour, due to the presence of iron, and slates made from such rock change colour after a time to a dirty green or brown.

Although the four slate beds above described are usually of considerable thickness in the Festiniog strata, yet it does not always pay to work them. For instance, where spar occurs the cleavage is often imperfect, being in some cases distorted into a curve of not more than 6 inches radius. Shining joints, in Welsh 'coeth,' frequently occur in the vicinity of spar. These run obliquely through the cleavage, and cause the slate to break.

'Posty' is a term applied to rock full of joints. These 'posts' often run parallel for a long distance to the strike of the beds, that is to say, at right angles to the plane of the dip. They vary in width from a few inches to upwards of 30 feet, and are composed of rock cut up by joints in every direction. Spar from 1 inch to 12 inches thick frequently traverses the hard rock in line with these posts. Immediately on each side of the posts the rock is sound, and solid blocks, 30 feet long, are sometimes obtained. Faults and great bevels are also frequently met with. In the vicinity of these the rock is generally broken, and unfit for being worked into slates. Great spars often pass through the slate beds, their general direction coinciding with that of the cleavage. They are sometimes made use of to form the roof for the openings. Cubes of sulphate of iron occur in the 'hard' and also in the workable slate; in the latter frequently in such minute particles as not to be discovered until after the slates are manufactured; slates containing it, however, become of a rusty colour after exposure to the weather.

Before opening a quarry, it is essential to ascertain the thickness and quality of the slate by driving trial levels: many ruinous blunders have been made owing to the neglect of this precaution.

It is, of course, always a matter of consideration whether it will be cheaper to proceed by the method of open quarrying or by mining. The former system is only advisable where the amount of overlying rock is comparatively small. In the Festiniog quarries the circumstances are such as to render mining in most cases preferable to open quarrying. The formation of the ground generally enables the water to be drained off by gravitation, and the rubbish has seldom to be raised by machinery.

One or more inclines (Plate 21, Fig. 1) have in most cases to be constructed to enable the manufactured slates to be removed from the quarry; and it can generally be arranged so that the loaded wagons draw up the empty ones. Although bad air, such as occurs in coal mines, is not found in slate quarries, yet it is necessary to provide ventilation to carry away the powder smoke. Mechanical means are seldom required for this purpose, good ventilation in most cases being obtained by sinking a shaft or driving a level.

It is convenient to have several mills for working the slate, one or more on each floor, thus obviating the necessity of raising the blocks from one floor to another. Although steam power is employed at a few quarries, yet water power, where it can be obtained, as is usually the case, is more economical. By having a water-wheel to each mill, the water is conveyed from one floor to another, and all the mills on the different floors are worked by one stream. Where it is necessary to lift the blocks from one floor to another, a water-balance is often employed, either working on an incline (Fig. 1), or in a vertical shaft.

The method of mining and opening out the chambers is as follows:—Assuming that it is proposed to work the 'Old Vein,' and that the 'flint bar' is to form the roof (Fig. 1), a level, A B, (Figs. 2 and 4) is first driven under the 'flint bar' about 7 feet wide, and 7 feet high, in the direction of the strike of the beds as far as the vein is worked out. After this level has been driven a roofing level, about 6 feet wide and 4 feet high, is commenced at the westernmost side of the opening, or 'bargain,' as it is termed, the roofing being more easily worked from this side, immediately under the flint bar (C D, Figs. 2, 3, and 4). Its direction on plan is in a line with the 'pillaring' of the slate, and consequently it makes an angle of about 75° in a westerly direction with the level A B (Fig. 2). When this inclined heading has been advanced some distance the roofing is commenced (C, Fig. 2), and is carried forward along the irregular line E F, the heading C D being kept somewhat in advance. This operation is continued

until the entire opening, or 'bargain,' is 'roofed,' the depth being about 4 feet, amply sufficient for the miners to work in. Under the roofing level, C D, a free side, or 'bôn,' is cut down in the plane of the pillaring, to obtain a face for the quarrying, the free side being in advance. Sometimes, however, the free side is completed before the quarrying is commenced, a favourable bevel joint extending downwards from the roof greatly facilitating the cutting, which, in such cases, is not necessarily at the western end of the chamber. When the rockmen commence quarrying out the blocks before the mining is completed, the mining of the roof is kept well in advance of the free side, and the free side in advance of the quarrying, the miners usually doing their work at night so as not to interfere with the quarrymen. The width, C E, of the 'bargain' varies from 30 to 120 feet, and is regulated by the appearance of the 'hard' forming the roof, and by the position of the bevels. For instance, where the 'hard' is solid, and not less than 12 feet in thickness, the width of the chambers may be about 90 feet. The thickness of the wall C H, on plan, is usually about half the width, C E, of the chamber, but in a thick slate bed a wider wall should be left.

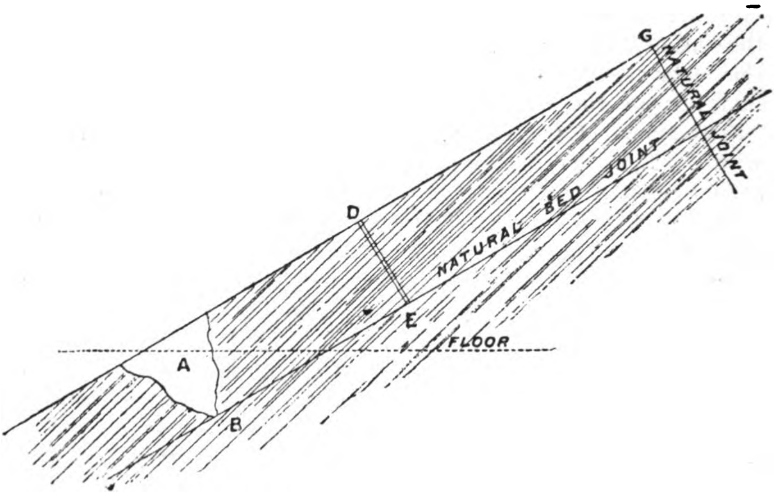
During the time that the works above described are being carried forward on floor No. 1, another horizontal level, A′ B′, is driven, and the same system of mining is carried out on floor No. 2, and perhaps on floor No. 3. The works on floor No. 1 should be in advance of the works on floor No. 2, and those on No. 2 in advance of those on No. 3. Care must be taken that the walls and openings are set out in line, so that the various chambers may ultimately form a series of openings, divided by the walls which have to be left permanently. The vertical distance between the several floors is about 50 feet. When the depth is much greater than this, care is required to prevent the slate blocks from the upper part of the chamber being broken in falling or sliding down. With shallow chambers, on the other hand, the mining work is more expensive, and much slate is destroyed in 'cutting the foot' near the level of the floor. In order to maintain the road A B on floor No. 1, as the slate is being worked out from beneath it on floor No. 2, it is necessary to suspend bridges of wood planking by chains or rods to the roof, I K (Figs. 3 and 4). Cross bridges, I L (Figs. 2 and 3), are also hung on the side of the wall. By these bridges, or platforms, the necessary roads are maintained until the slate is worked out of all the chambers.

In blasting the rock the miners chiefly use compressed gun-

cotton. A common practice is to charge a hole about 2 feet deep with two cartridges of $\frac{7}{8}$-inch compressed gun-cotton, each 1 inch long, with a layer of 2 or 3 inches of ordinary blasting powder over them. This statement, however, applies to the miners' operations only. The rockmen never use gun-cotton, as it shatters the blocks. Cotton fuse is invariably employed, having quite superseded the straw fuse. For driving a level, or for removing the hard rock, oil of glycerine is effective.

The process of quarrying the blocks is chiefly regulated by the position of the natural joints, or bevels, which occur every 3 to 8 feet in depth, and to which the rock may be worked off.

FIG. 5.

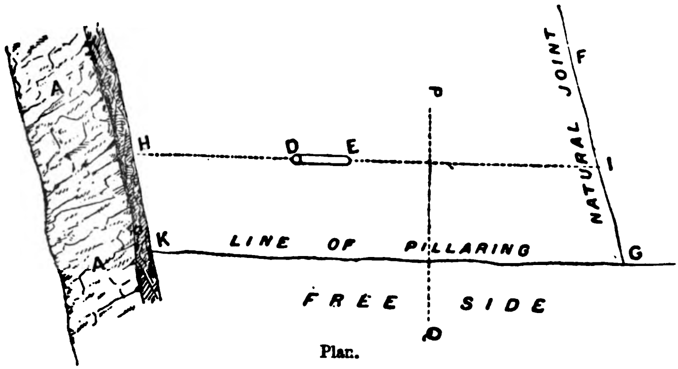


Section through H I on Plan.

Before this can be done, however, the rock must be liberated at the foot at the floor of the chamber. If there is no joint running with the strike of the beds, the rockmen must 'cut the foot,' as it is termed; that is, remove by blasting a portion of rock, an operation often injuring good slate. Cutting machines have been used for the purpose. Having liberated the rock at the foot, the quarrymen proceed to cut out a block by drilling a hole, about $1\frac{1}{4}$ inch in diameter, by a jumper. The hole, D E, is made from 4 to 6 feet from the face of the free side, at right angles to the bed, down to the next natural bed joint (Figs. 5, 6, and 7). It is charged to the top with ordinary powder, no tamping

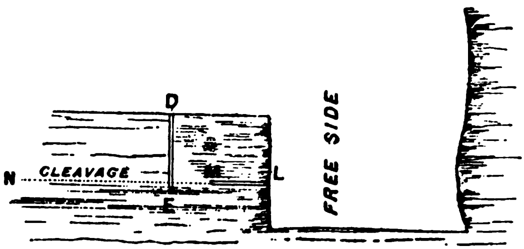
being used. When fired the rock is generally broken in a line with the pillaring of the slate, the crack probably extending until it meets with a natural cross joint, thus liberating a block. If the first charge is not sufficient to effect this, a second is put in, and sometimes a third. Great care is taken not to employ a stronger charge than necessary, as the block would be much injured thereby, or be what is called 'powder split.' An ordinary charge

FIG. 6.



Plan.

FIG. 7.



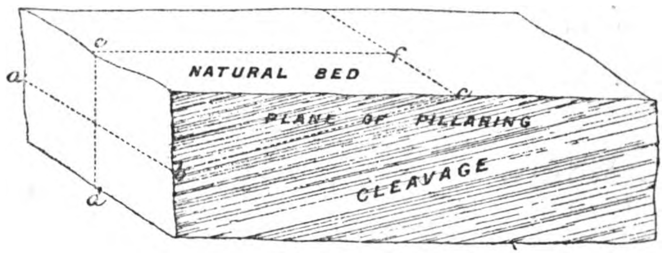
Section through P Q on Plan.

with tamping would render the block quite unfit for slate-making, and perhaps injure the surrounding slate. The charge is intended just to move the block and no more; so careful, indeed, are the men in this respect, and such confidence have they in the result, that they sometimes stand upon the block whilst the shot is being fired. When a bed joint is not met with at a suitable depth a shot, M L, is inserted about 2 or 3 feet into the

rock from the free side in a horizontal direction, parallel to the natural bed joint (Fig. 7); it is then charged with a depth of 2 or 3 inches of powder and of 2 or 3 inches of tamping, formed of slate dust loosely put in. The shot splits the rock along the cleavage, and the pillar shot is then fired.

The slate block thus obtained, about 12 feet long by 4 feet wide, is first split into two parts by a hammer and chisel along the cleavage (Fig. 8), then again in the same manner along the pillar-

FIG. 8.



ing of the slate. If the direction of the pillar split is found not to be quite in the proper line, a hole is drilled through the block in the true line, and a plug and feather inserted to split it. The same process of splitting the block in each direction is repeated several times until it is reduced to slabs about 14 inches wide and 4 inches thick, which are now ready for the saw table.

If any of these slabs are of too great a length for the table (more than 5 or 6 feet), they are placed across supports and broken in two with a large wooden mall, being first nicked with a chisel. The operation of splitting the blocks, into slabs fit for the saw table, is not all performed in one place, being partly done in the chamber or 'bargain,' where the blocks are quarried, and partly at the mill. For instance, the blocks above described would first be reduced into pieces weighing not more than 3 or 4 tons, and then be removed to the vicinity of the saw table, where the process of splitting would be completed. For this purpose they are lifted by a crane into trucks, and are then taken to the mill.

The slabs are cut to the required length by a circular saw kept wet as it revolves, so that the sawn surfaces may not be heated, otherwise their splitting properties would be impaired; and the table top is drawn forward by a feed-motion towards the saw.

Slates measuring 20 inches by 10 inches are worth more per ton than those of either a larger or a smaller size. The slabs from the

saw table are split from the sawn surface along the cleavage by a fine and broad chisel, with one or two blows of a light wooden mallet. The slab, which is from 3 to 4 inches thick, is first split into two equal thicknesses, and these are repeatedly bisected until they are reduced to laminæ. They are then ready for the dressing machine, of which there are several descriptions. All have a steel blade about 3 feet long, which is made to rise and fall, or to revolve over another fixed blade, thus acting like a pair of shears. A gauge is attached to the frame of the machine to insure the squareness of the slates and to regulate their size. During the operation, the slate is held in such a position that the descending blade cuts out the largest slate that the piece will admit of. The dressing machine is generally worked by mill power, but sometimes by the man cutting the slates. Only a small portion of the slate is made into slabs for sale. The blocks, when split to the necessary thickness, are sawn round the edges to the size required (when the slate is of good quality with a straight and even split); this completes the operation, the slabs being termed 'self-faced.' When, however, the surface is not true, they are planed by a chisel from 4 to 15 inches broad, according to the hardness of the slate. The slate is made to pass repeatedly under the chisel until the surface is uniform, and the slab reduced to the required thickness. In some of the best 'bargains' in the Festiniog district, the proportion of manufactured slates to rock quarried has been 1 in 4, equivalent to about 1 ton of slates for 2 cubic yards of rock, but the average proportion is probably only 1 in 5. Under favourable circumstances, 1 ton of slates to 7 cubic yards of rock will pay for working, leaving a small profit. But this does not include the rock removed by the miners in preparation for the quarrymen.

Much skill is required to cut up the blocks to the best advantage. A slate block of a favourable shape, weighing 1 ton, will, with care, produce about ½ ton of slates, but, on the average, such a block would only produce about ¼ ton of manufactured slates. From 20 to 90 tons of slates per month may be obtained from each 'bargain,' depending upon the quality of the rock. Sometimes a wide chamber is let in two contracts or 'bargains.' A chamber 60 feet wide might be so let. Formerly, and even now at some quarries, the slates were made entirely by hand without sawing tables or machine slate-dressers, and much waste was the result. The slabs were broken across by a large mallet, and cut by hand with a heavy knife. The rubbish from the chambers is removed to the tip in wrought-iron wagons, weighing about 10 cwt. and holding

about 50 cwt. The wheels of the wagons are either single flanged fast on the axle, or double flanged loose on the axle; the latter are better suited for sharp curves. The tramways for the transport of the blocks and rubbish are of a simple kind, and not unfrequently consist of flat wrought-iron bars let into oak cross sleepers; a convenient form of rail on sharp curves.

The cost of a sawing table and slate-dresser is about £60, and they work about 1 ton of manufactured slate per day on an average, but with good rock much more. A sawing table requires ½ HP. to drive it, but the power varies according to the sharpness of the saw and the hardness of the rock. The saws are sharpened twice a day. They make fifty revolutions per minute, and the feed-motion given to the table is about 6 inches per minute; sand saws are now seldom used.

The level, which is driven at the commencement of the work, (A B, Plate 21, Figs. 2 and 4) measures about 7 feet square, and is generally let to the miners for £2 10*s.* per yard forward. This price includes the cost of removing the rubbish to the tip, and powder and other stores. Two miners work together at the face, single hand drilling. With two shifts they drive about 15 inches in twenty-four hours. Four holes, 2 feet deep, constitute a day's work. The average cost per lineal yard of heading is—

		£.	*s.*	*d.*
Labour—four men, 9·5 days at 4*s.*		1	18	0
Stores	Candles	0	2	0
	Fuse	0	1	0
	Gun-cotton	0	3	0
	Black powder	0	3	0
	Smith	0	0	6
Removing rubbish to tip, 10 tons at 4*d.*		0	3	4
Sick fund, 1*s.* per man per month		0	0	4
		£2	11	2

The expense, however, varies from £2 to £3 per lineal yard, according to the direction of the heading, the lay and hardness of the slate rock, the quality of the roof, and the number of joints. The cheapest description of level to drive is one running with the strike of the beds, with a good clay slant for a roof, also in 'posty' rock. The average progress with two shifts of two men per day is from 8 to 12 lineal yards a month. The miners often work three shifts of eight hours per day, and under these circumstances, in favourable ground, the rate of progress has been 22 lineal yards in five weeks—about 18 lineal yards per month.

In the 'flint' or 'hard' rock, in which nitro-glycerine and gun-cotton are effective, the cost of a level 7 feet square in section varies from £6 to £9 per lineal yard. With two shifts of miners the progress is from 3 to 5 lineal yards per month. For a level 6 feet by 4 feet the cost is from £1 to £2 per lineal yard, according to the character of the roof. With two shifts of one man per day the progress varies from 6 to 12 lineal yards per month.

For widening the roofing the charge is from 5*s.* to 8*s.* per superficial yard, including the stores and labour, but exclusive of moving the rubbish to the tip. The lower price is paid when under a clay slant roof. Several men may be employed at the same time at this work. Should the rock be of such quality as to be useless for slate-making, the cost of quarrying and removing it as rubbish to the tip will be, approximately,

	Per Ton.	
	d.	
Quarrying	5	
Removing to tip	4	
	9	or about 1*s.* 6*d.* per cubic yard, the contractor finding powder, &c.

If, however, the slate has to be quarried from an unfavourable position, the cost may be 2*s.* per cubic yard, or more.

A 'bargain' ready for work may be let to the contractor in several ways:—

1. The contractor may be paid a price per ton on the blocks quarried and taken to the mill, together with a price per ton for rubbish quarried and removed to the tip, and also a price per mille (or nominal thousand) for manufactured slates.

2. A price per ton for all rock quarried, whether taken to the mill or removed as rubbish to the tip, and a price per mille for manufactured slates.

3. A price paid to the contractor on the manufactured slates, to include the cost of quarrying, &c.

Supposing the rock to be of such quality that 1 ton of manufactured slates can be obtained from 7 cubic yards, or a ratio by weight of 1 in 14; then, if the bargain is let to the contractor on the plan indicated by the second of the above-named methods, the prices paid to the contractor would be about 6*d.* per ton for all rock quarried, together with a price per mille for slates made, equivalent, in the present instance, to 20*s.* per ton of manufactured

slates. Under these circumstances the expense per ton for quarrying and making slates is, approximately,

	Tons.	£.	s.	d.
Blocks quarried and rubbish removed from the quarry to the tip	14 at 6*d*.	0	7	0
Price paid on the manufactured slates . . .	1 „ 20*s*.	1	0	0
Total amount paid to contractor . . .		1	7	0
Add for mill rubbish taken from the mill to the tip	4 „ 4*d*.	0	1	4
Total cost per ton of manufactured slates .		£1	8	4

This price is exclusive of the cost of preliminary operations, such as opening out the ground and driving the levels. The charge for these varies so much with each quarry that it would be impossible to reduce it satisfactorily to a price per ton of manufactured slates. The cost per ton of slates given above, viz., £1 8*s*. 4*d*., is for a yield of 1 in 14. For a yield of 1 in 7 by weight, the cost of manufactured slates might perhaps not be more than 15*s*. per ton. With a good yield of rock, as in this case, the mode of payment described under the third method is the best to adopt, viz., to pay the contractor only upon the slates made, in order to induce him to waste as little rock as possible. When the yield of the rock is poor, however, the contractor is generally paid according to the system given under methods 1 and 2.

In exceptional cases, where the slate-making is let as a distinct and separate contract from the quarrying, the cost, including splitting up the blocks and sawing and dressing the slates, is 10*s*. per ton.

The price paid to the contractor per mille on the manufactured slates varies from time to time, and depends also upon the size of the slates. In order to simplify the calculations, the following method is generally used. Certain standard prices are assumed for each size of slates; thus, for a large slate 24 inches by 14 inches, the standard or nominal price is 30*s*. per mille; for slates measuring 20 inches by 10 inches, 20*s*.; for a slate 14 inches by 10 inches, 10*s*. per mille; and for intermediate sizes there are intermediate prices. Then the number of slates of each kind being estimated at these nominal prices, and the amounts added together, the sum of the whole is increased by a certain percentage, called 'poundage,' agreed upon for that particular bargain. Thus a 'pound poundage' is equivalent to adding 100 per cent., or doubling the nominal amount. This poundage varies from

5s. to 25s., and is therefore equivalent to adding from 25 to 125 per cent. to the prices given above.

The cost of slab manufacture, exclusive of quarrying, is as follows:—

	Per Super. Yard.
	d.
Splitting up and sawing the block	5
Planing both sides	4
Total cost	9

For slabs $1\frac{1}{4}$ inch thick this is equivalent to 10s. per ton.

The average wages made by the men are:—

	Per Day. s.	d.
Slate-maker or planer	6	0
Miner	4	0
Labourer	3	6

A mille is more than a thousand slates; for instance, the quarryman as a rule gives to the quarry 1,300 slates to the mille; the quarry send to the wharf for shipment 1,280 per mille; and the wharf ships 1,260 per mille to the merchant, who in addition is allowed 12 per mille to cover breakage, but this is a matter of arrangement between the buyer and seller. The breakage in transit is not always covered by the above allowance of 12 per mille, especially if the slates are not quite straight.

The proprietors of the quarries are almost exclusively Englishmen; but the quarrymen are entirely Welsh, only about 2 per cent. of them speaking English. Although some of the quarries return large profits to their proprietors, many of them are at present worked at a loss. The largest and most profitable is that owned by the Welsh Slate Company, which ships about 40,000 tons annually. The entire produce of the Festiniog district is 140,000 tons per annum, representing an annual value of between £400,000 and £500,000.

The slates are conveyed by the 2-feet gauge railway from Festiniog to Portmadoc. The full wagons run down by their own gravity, the gradient being a descending one all the distance. About 120,000 tons of slate are shipped from Portmadoc, some to London, but for the most part to the Continent, where the blue varieties are preferred; the remainder go by rail to various parts of England.

The communication is accompanied by a series of sketches, from which Plate 21 and Figs. 5, 6, 7, and 8 have been compiled.

[APPENDIX.

APPENDIX.

List of Authorities on Slate and Slate Quarrying.

Anonymous. "A few words on Slate, Slate Quarries, and Slate Quarry Companies." By a Man of Experience.

Bower, John. "Slate Quarries as an Investment." 8vo. London, 1865.

Hughes, Samuel. "The Bangor Slate Quarries," Weale's "Quarterly Papers on Engineering." 4to., vol. iii., 1845.

Kellow, Joseph. "The Slate Trade in North Wales." 8vo. London, 1868.

Ramsay, Andrew C. "Memoirs of the Geological Survey of Great Britain," vol. iii. "The Geology of North Wales," p. 75. 8vo. London, 1866.

Smith, T. Cooper. "Slate Quarries in Wales considered as an Investment."

No. 1,486.—"On the Resistance of Boiler Flues to Collapse." By Professor WILLIAM CAWTHORNE UNWIN, B.Sc., Assoc. Inst. C.E.

UNTIL the year 1858 little or nothing was known as to the resistance of cylindrical vessels to an external or collapsing pressure. About that time the failure of some boiler flues led the late Sir William Fairbairn, Bart., M. Inst. C.E., to suspect that the strength of this part of a boiler, as then constructed, was often little greater than the working pressure to which it was subjected. With the aid of the Royal Society[1] and the British Association[2] a series of experiments were carried out, which to a great extent confirmed Sir W. Fairbairn's surmise; and since the publication of these experiments the construction of all boiler flues has been modified, in accordance with the general rules deduced from the experiments.

There was no attempt in these papers to state any theory of collapse. A purely empirical formula was obtained, agreeing very closely with the experimental results. Let t = the thickness, l = the length, and d = the diameter of a cylindrical vessel subjected to an uniform external pressure, d, t, and l being all expressed in inches. Let p be the collapsing pressure in lbs. per square inch. Then, according to Fairbairn,

$$p = 9{,}672{,}000 \frac{t^{2 \cdot 19}}{l\,d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When the flue is of ordinary thickness ($t = \frac{3}{8}$ inch to $\frac{3}{4}$ inch) the following approximate rule is sufficiently accurate:—

$$p = 9{,}672{,}000 \frac{t^{2}}{l\,d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

Since the date of this inquiry two other attempts have been made to obtain a formula from the experiments. In the "Verhandlungen des Vereines zur Beförderung des Gewerbefleisses in Preussen," Jahrgang 1859 and 1870, there is an investigation leading to the following formula:—

$$p = 1{,}033{,}620 \frac{t^{2 \cdot 081}}{l^{0 \cdot 564}\, d^{0 \cdot 8:9}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

[1] *Vide* Phil. Trans. 1858, p. 389.

[2] *Vidé* British Association Report, 1857, p. 215.

Both these formulæ are obviously defective in making the collapsing pressure decrease indefinitely with increase of length. As this cannot be the case, M. Love proposed a formula of a different form. In the "Civilingenieur," Jahrgang 1861, this formula is investigated and new co-efficients deduced for it by the method of least squares. The formula, reduced to English measures, is

$$p = 5,358,150 \frac{t^2}{l\,d} + 41,906 \frac{t^2}{d} + 1,323 \frac{t}{d} \quad . \quad (3)$$

This formula is based to a certain extent on theoretical considerations bearing on the probable limit of decrease of collapsing pressure with increase of length, and it no doubt represents very closely Fairbairn's experiments.

The formulæ given above are sufficiently discordant. None of them are more than empirical expressions based on a limited series of experiments. They have no relation to ordinary formulæ of applied mechanics, which would enable a judgment to be passed as to how far their form is correct, and they leave entirely uncertain the limits within which they are to be applied.

It appears, therefore, that a re-examination of these researches is not superfluous. If it proves possible to show that the collapse of flues can be expressed by the ordinary laws of resistance of materials, three important objects are gained. (1). The nature of the process of collapse will be better understood. (2). The formula of collapse will be worthy of more confidence, because it will no longer depend on these experiments alone. (3). The limits within which the formula is applicable will be more or less clearly ndicated.

Sir W. Fairbairn's experiments may be classified thus:—

(1). Experiments on thin tubes. In this series all the tubes were 0·043 inch thick, and they varied in length from 15 inches to 60 inches, and in diameter from 4 inches to 12 inches. The tubes were of tin plate (iron plate tinned), and they were both riveted and soldered, so that they were as strong at the riveted joint as elsewhere. The tubes in this series were more perfect in form than the thicker tubes, and they were all constructed in exactly the same way. They afford, therefore, the best basis for determining the influence of the length and diameter on the strength.

(2). Experiments on thick tubes. These experiments were much less numerous than those on thin tubes, and hardly two of the tubes were constructed in exactly the same way. Some had

lap joints, others butt joints, and in one there were cross joints in addition to the longitudinal joint. Three were somewhat elliptical. These experiments must be used in determining the influence of the thickness on the strength, but care must be taken to compare only experiments on similar tubes.

(3). Two experiments are given on actual boiler flues, and to these can be added one or two experiments since made.

Experiments on Thin Tubes.

The following table contains all the experiments on thin tubes. Those marked with an asterisk were not used by Sir W. Fairbairn in reducing his results and obtaining the constants for his formula.

Table I.—Experiments on Thin Tubes.

No. of Experiment.	Diameter in inches. d.	Length in inches. l.	Thickness in inches. t.	$\frac{l}{d}$	Collapsing Pressure in lbs. per sq. inch.
5	4	60	·043	15·00	43 mean
27	4	60	..	15·00	47 45
3	4	40	..	10·00	65
4	4	38	..	9·50	65
29	4	30	..	7·50	93
6	4	20	..	5·00	140
1	4	19	..	4·75	170 mean
2	4	19	..	4·75	137 153½
30*	4	15	..	3·75	147
9	6	59	·043	9·90	32
7	6	30	..	5·00	48 mean
10	6	30	..	5·00	52 55
11	6	30	..	5·00	65
8	6	29	..	4·85	47
25*	8	60	·043	7·50	22
14	8	39	..	4·85	32
15	8	40	..	5·00	31
13	8	30	..	3·75	39 mean
26*	8	30	..	3·75	36 37½
16	10	50	·043	5·00	19
17	10	30	..	3·00	33
19	12	60	·043	5·00	12½
18	12·2	58½	..	4·80	11
20	12	30	..	2·50	22

A slight examination of the table will show that the length of the tube greatly influences the collapsing pressure; in fact, as was observed during the experiments, the collapsing pressure varies

nearly inversely as the length, for tubes of the proportions embraced in the experiments. This remarkable law was entirely unexpected, and it appeared so singular, that further experiments were made on the influence of the length on the strength of tubes subjected to an internal pressure. But it was found that, when the pressure was internal, the length had no sensible influence on the strength; so that in this respect the laws of resistance to an external and to an internal pressure are entirely different.

The difference in these two cases shows that:—(1). The ends of the tube do not sensibly influence the circumferential stresses in the tube. (2). Since in collapse a tube gives way by 'buckling,' which is due to a combination of direct circumferential stress and bending action, the action of the ends must in some way modify the bending action at the moment of collapse.

That the length of the tube does modify the bending action may easily be shown, though the fact has not hitherto been noticed. Sir W. Fairbairn has given figures of the collapsed tubes. They show that the originally circular tube bent during collapse into figures of the following forms:—

a b c d

These figures consist of arcs, alternately of convex and concave curvature. At *d* there are four curved arcs, and four points of contrary flexure; at *c* there are six arcs, at *b* eight arcs, at *a* ten arcs. Consider a strip of the tube 1 inch wide; let p be the pressure per square inch to which the tube is subjected, λ the length of one of the curved arcs. The total uniformly distributed load on one arc of such a strip is $p\lambda$ lbs. The resistance to bending is

$$p\lambda = \frac{4}{3} f \frac{t^2}{\lambda}$$

$$\therefore p \propto \frac{1}{\lambda^2} \quad \ldots \ldots \ldots \ldots \quad (4)$$

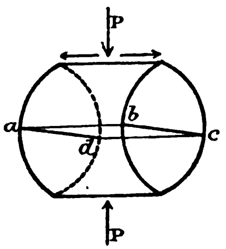
That is, the collapsing pressure necessary to produce the bending varies inversely as the square of the length of the arc. The collapsing strength of the tube must therefore depend on the number of arcs into which the tube divides at the moment of collapse. If

it can be shown that the length of the tube influences the number of arcs into which the tube divides, a step will have been gained towards explaining the influence of the length on the strength of a tube subjected to external pressure. That the number of arcs into which the tube divides does depend on the length is conclusively shown in the following table, which contains all the experiments on thin tubes, arranged in the order of the ratio of length to diameter:—

TABLE II.—DEPENDENCE of the FORM of the COLLAPSED TUBE on the RATIO of LENGTH to DIAMETER.

No. of Experiment.	Ratio $\frac{l}{d}$	No. of Arcs into which the Tube divided at the moment of Collapse.
5	15·00	4
27	15·00	4
3	10·00	4
9	9·90	4
4	9·50	4
29	7·50	4
25*	7·50	6
6	5·00	6
7	5·00	6
10	5·00	6
11	5·00	6
15	5·00	6
16	5·00	6
19	5·00	6
8	4·85	6
14	4·85	6
18	4·80	6
1	4·75	6
2	4·75	6
30*	3·75	8
13	3·75	8
26*	3·75	8
17	3·00	10
20	2·50	8

Consider a slice of the flue of length b; the resultant pressure P on either side of a diametral plane $= p\,d\,b$. This produces on



radial sections ab, or cd of the flue a thrust, the amount of which is,

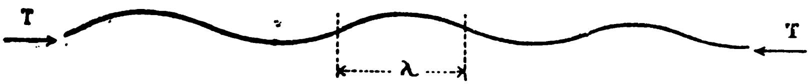
$$T = \frac{p\,d\,b}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Hence the metal of the flue is in the same condition as a straight column of length πd subjected to a compression of the same intensity T. In investigating the strength of flues, the well-known laws of resistance of long columns may be applied.

Greatest Pressure consistent with Stability in long Columns.

The only rational theory of the resistance of long thin columns is due to Euler. It is based on the assumption that the elasticity of the material is unimpaired at the moment of giving way. It is therefore not strictly applicable to determine the ultimate resistance of long columns. Hodgkinson's experiments show in what way Euler's formulæ must be modified in certain cases, and this will be considered hereafter. Meanwhile let Euler's theory be assumed to be applicable to the present case.

Fig. 1.



Let Fig. 1 represent a long thin column bent into a symmetrically waved form, and let T be the thrust acting along the column. Then Euler shows that if T is less than a certain value, the column will straighten itself; but if it be greater than a certain value the column will be crumpled up. Suppose a straight column subjected to such a thrust. No increase of the thrust will directly produce bending; but if there is a bending of the column, however small, due to original want of straightness or to want of coincidence of T with the axis of the bar, then there is some value of T at which the column will crush up. That value of T is the greatest load consistent with the stability of the column. Let λ be the length of an arc of the column, measured between two points of contrary flexure. Then, on Euler's theory,

$$T = \pi^2 \frac{I\,E}{\lambda^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where I is the moment of inertia of the section of the column, about an axis through its centre of figure and perpendicular to the

plane of bending; E is the modulus of elasticity of the material, and T is the greatest thrust consistent with stability.

For a rectangular section $I = \frac{b\,t^3}{12}$; then

$$T = \frac{\pi^2 E}{12} \cdot \frac{b\,t^3}{\lambda^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

For a column of cylindrical form $I = \cdot 0491\, d^4$

$$T = \cdot 0491\, \pi^2 E \frac{d^4}{\lambda^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The latter equation will be required presently for comparison with Hodgkinson's experiments.

Collapsing Pressure of Tubes deduced from Euler's Formula.

Equating (5) and (7)—

$$\frac{p\,d\,b}{2} = \frac{1}{12} \pi^2 E \frac{b\,t^3}{\lambda^2}$$

whence,

$$p = \frac{1}{6} \pi^2 E \frac{t^3}{d\,\lambda^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Suppose the tube gives way symmetrically, so that $\lambda = \pi\, d \div n$, where n is the number of arcs into which the tube divides in collapsing,

then,

$$p = \frac{E}{6} \cdot \frac{n^2\, t^3}{d^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

a formula for collapse entirely independent of Fairbairn's experiments. It will be shown presently that in these experiments $n^2 = \frac{\pi^2\, d^2}{a\, l}$ approximately, where l is the whole length of the tube. Inserting this value,

$$p = \frac{\pi^2 E}{6\,a} \cdot \frac{t^3}{d\,l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

a formula almost identical in form with Sir W. Fairbairn's, but obtained in an entirely different manner.

It would seem, therefore, at first sight, that nothing new had been obtained which had not already been found by direct examination of the experiments. This, however, is not the case. By reducing collapse to a case of pillar resistance, known co-efficients can be brought to bear on the determination of the constants, so

that entire dependence need not be placed on the collapse experiments. This will be found of importance presently. Then also, from the mode in which the formula is obtained, the limits within which it can be applied may be assigned.

It does not seem possible for a tube to divide into less than four arcs. Hence the least value of n is four, and the tube reaches its minimum strength when

$$l = \frac{\pi^2 d^2}{16\,a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

If l is increased beyond this limit, the strength does not decrease with the length, but remains constant.

The lowest collapsing pressure for long tubes is then,

$$p_{\text{min.}} = \frac{8}{3} \mathrm{E} \frac{t^3}{d^3} = 76{,}000{,}000 \frac{t^3}{d^3} \quad . \quad . \quad . \quad (13)$$

Euler's formula ceases to be applicable when $\lambda < 28\,t$, and this gives another limit to the application of the formula. If l is less than this, the formula ceases to be applicable, and the collapsing pressure at the limit is

$$p_{\text{max.}} = \frac{\pi^2 \mathrm{E}\, t}{4704\, d} = 58{,}800 \frac{t}{d} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

The two limits coincide, when $t = \frac{1}{36} d$. If t is greater than this the formulæ cease to be applicable.

The theory has been stated in this general form for simplicity. It requires, however, some modification to make it agree with the experiments. It has been already pointed out that Euler's formula is not strictly applicable to determine the ultimate strength of long columns, because it assumes that the elasticity remains unimpaired at the moment of giving way, or that the elastic limit for the material is not passed. In the next place, a careful examination of the experiments shows that, although the tube divides in an approximately symmetrical manner, it does not divide with exact symmetry. It follows from this that λ is not an exact aliquot part of $\pi\, d$.

Comparison of Euler's Formula with Hodgkinson's Experiments.

Hodgkinson showed that Euler's formulæ require some modification when applied to determine the ultimate strength of long columns. In comparing Euler's formula and Hodgkinson's experiments, it must be observed that the length λ in Euler's

formula corresponds with the length of one of Hodgkinson's columns with rounded ends. Hodgkinson's experiments are almost all on cylindrical columns, and most of them are on columns of cast iron. There are only four on wrought-iron columns directly available for comparison with Euler's formulæ, but the experiments were made with so much care, that the results may be taken to have great importance.

Euler's formula for cylindrical columns is (8),

$$T = \cdot 0491\ \pi^2 E \frac{d^4}{\lambda^2}$$

Putting E = 28,500,000 for wrought iron

$$T = 13{,}811{,}000 \frac{d^4}{\lambda^2} \quad . \quad . \quad . \quad . \quad (15)$$

Hodgkinson deduces from his experiments on wrought-iron columns [1]

$$T = 13{,}802{,}112 \frac{d^{3\cdot 76}}{\lambda^2}. \quad . \quad . \quad . \quad (16)$$

This agrees so closely with Euler's formula, except in one respect, that Euler's formula may be assumed to be sensibly true for wrought iron, with that one exception. Hodgkinson's experiments show that the strength does not increase quite so fast as the fourth power of the diameter, and hence it may be inferred that it does not increase quite so fast as the cube of the thickness in rectangular columns.

In the experiments on cast-iron columns, it was found that the strength did not decrease quite so fast as the square of the length.

Probable Length of the Arcs into which the Tube divides at the moment of Collapse.

The tube does not divide in a perfectly symmetrical manner, and collapse is determined by the giving way of the weakest, in other words, of the longest of the segments into which the tube divides.

As Hodgkinson made no experiments on rectangular columns, Eq. (7) may be taken for the resistance of long rectangular columns, bearing in mind that it will probably be necessary to reduce a little the index of the thickness when discussing the influence of the thickness on the strength. As all the tubes now

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[1] Phil. Trans. 1840, p. 424.

considered are of the same thickness, it will make no sensible error to retain the index as it stands. Putting E = 28,500,000, then

$$T = 23{,}440{,}000 \frac{b\,t^3}{\lambda^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Combining this with Eq. (5),

$$p = \frac{46{,}880{,}000\, t^3}{d\,\lambda^2}$$

and putting $t = \cdot 043$, then

$$\lambda = \frac{61 \cdot 05}{\sqrt{p\,d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where λ is the length of the longest of the arcs into which the tube divided at the moment of collapse, deduced from the collapsing pressure. In the following table the values of λ are obtained from the observed collapsing pressures, and compared with the mean lengths of the arcs into which the tube divided, as shown by the form of the collapsed tube. The mean length is $\pi\, d \div n$, where n is the number of segments in the collapsed tube. It will be seen that the difference is never so great that λ would correspond to a different value of n.

No. of Experiment.	d.	l.	$p\,d$.	n.	Mean Length of Segments of Tube.	Length of longest Segment. λ.
5	4	..	180	4	3·14	4·55
27	4	..				
3	4	..	260	4	3·14	3·79
9	6	..	192	4	4·71	4·41
4	4	..	260	4	3·14	3·79
29	4	..	372	4	3·14	3·17
25*	8	..	176	6	4·19	4·60
6	4	..	560	6	2·09	2·58
7	6	..				
10	6	..	330	6	3·14	3·36
11	6	..				
15	8	..	248	6	4·19	3·88
16	10	..	190	6	5·24	4·43
19	12	..	150	6	6·28	4·99
8	6	..	282	6	3·14	3·64
14	8	..	256	6	4·19	3·82
18	12·2	..	134	6	6·40	5·27
1	4	..	614	6	2·09	2·46
2	4	..				
30*	4	..	588	8	1·57	2·52
13	8	..	300	8	3·14	3·52
26*	8	..				
17	10	..	330	10	3·14	3·36
20	12	..	264	8	4·70	3·76

In the following table the values of λ are arranged so as to show in what way they vary with the length and diameter of the tube :—

			$d =$		
$l =$	**4**	**6**	**8**	**10**	**12**
60	4·55	—	4·60	—	4·99
59	—	4·41	—	—	—
58½	—	—	—	—	5·27
50	—	—	—	4·43	—
40	3·79	—	3·88	—	—
39	—	—	3·82	—	—
38	3·79	—	—	—	—
30	3·17	3·36	3·52	3·36	3·76
29	—	3·64	—	—	—
20	2·58	—	—	—	—
19	2·46	—	—	—	—
15	2·52	—	—	—	—

This table shows that λ increases with l nearly in proportion to $\sqrt{l}$, and that it also increases a little with d. A careful reduction of the results gives

$$\lambda = 0 \cdot 6375\, l^{0 \cdot 45}\, d^{\cdot 08} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

as the best average value.

Introducing this in Eq. (18), there is obtained for the collapsing pressure of tubes 0·043 inch thick

$$p = \frac{9170}{l^{\cdot 9}\, d^{1 \cdot 16}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

Fairbairn's formula for these tubes is

$$p = \frac{9838}{l\, d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

which is not widely different, though obtained in an entirely different manner.

The limits within which the formula is applicable can now be exactly defined.

From Eq. (18) $\qquad p = \dfrac{3727}{\lambda^2 d}$

Supposing the tube to divide into four arcs, and allowing some excess of length to the longest segment, it is obvious that λ could

not be greater than a semicircle or $\frac{1}{2}\pi d$. Taking $\lambda_{max.} = 1\cdot5\,d$, which is a little less than this,

$$\lambda_{max} = 1\cdot5\,d = \cdot6375\ l_{max.}^{0\cdot45}\ d^{\cdot06}$$
$$l_{max.} = 6\cdot682\,d^{2\cdot04}$$
$$= 6\cdot7\,d^2,\ \text{very nearly.}$$

That is, the tube reaches its minimum strength when the length is about $6\cdot7d^2$ inches long. Thus a 4-inch tube would be of minimum strength when 107 inches long. If the length were increased the strength would remain the same.

On the other hand, Euler's formula ceases again to be applicable if l is so small that $\lambda < 28\,t$

$$\lambda_{min.} = 28\,t = \cdot6375\ l_{min.}^{0\cdot45}\ d^{\cdot06}$$
$$l_{min.} = 4468\ \frac{t^{2\cdot22}}{d^{0\cdot13}}.$$

In these formulæ $l_{max.}$ and $l_{min.}$ are the greatest and least lengths to which the formula for collapse is applicable.

The two limits coincide if $t = \frac{d}{19}$. For greater values of t the formulæ cease to be applicable.

Experiments on Thick Tubes.

The table on the next page contains all the experiments made by Sir W. Fairbairn on tubes thicker than 0·43 inch, together with two experiments on actual boiler flues given in his memoir. Two other experiments are added, which have been made since. No. 53 was communicated to the Author by Mr. Alfrey. It was an old flue, originally $\frac{3}{8}$ inch thick but reduced to $\frac{5}{16}$ inch by corrosion. There were four longitudinal lap joints in the circumference of the flue and four circumferential lap joints in its length. The flue collapsed over an arc of about one-eighth its circumference, the collapsed part extending about one-half the length of the flue. Experiment 54 is from Jullien's "Machines à Vapeur," p. 240. The details are not given so fully as is desirable, but the experiment is interesting from the exceptional dimensions of the flue. The flue is said to have given way three times successively.

Experiment 31 must be rejected for the reasons given in Fairbairn's memoir. It was no doubt flattened while being caulked.

These experiments are not numerous enough to indicate the influence of diameter and length with exactness. It must therefore be assumed that the same rule is applicable as has been found to obtain with thin tubes.

EXPERIMENTS ON THICK TUBES.

Number of Experiment.	Diameter. d.	Length. l.	Thickness. t.	Collapsing Pressure. p.	Jointing of Tube.
23	9	37	·14	262	Longitudinal lap joint.
22	$18\frac{3}{4}$	61	·25	420	
31	15	21	·125	150?	
24	9	37	·14	378	Longitudinal butt joint.
33	$14\frac{5}{8}$	60	·125	125	Longitudinal and circumferential joints.
51	42	420	·375	97	
52	42	300	·375	127	
53	$33\frac{1}{2}$	360	·34	99	
54	7·87	276	·157	110	

According to Euler's theory the collapsing pressure should vary as the cube of the thickness of the tubes. Hodgkinson's experiments show that in long columns the strength varies about as the 2·76th power of the thickness. But in these tubes it may be expected that the strength will vary as a somewhat lower power of the thickness. The tubes having lap joints cannot be perfectly cylindrical, and the deviation from the cylindrical form increases with the thickness of the plates. In tubes with butt joints the deviation from the true form is not so great. Ordinary flues have both longitudinal and cross joints, and the latter stiffen the tube. In addition to this, in a tube consisting of several plates the line of the longitudinal joint is broken, and this partly neutralises the deviation from the true form.

Assuming that the collapsing pressure is given by a formula of the form

$$p = c \frac{t^n}{l^{0\cdot 9}\, d^{1\cdot 1}}$$

and taking the experiments on thin tubes as a starting-point of the comparison, then the following are the values of the constants c and n deduced from the experiments above.

For tubes with a lap longitudinal joint:

Experiment.	n.	c.
23	1·90	5,368,000
22	2·28	9,358,000
Means . .	2·1	7,363,000

For tubes with butt longitudinal joints:

Experiment.	n.	c.
24	2·21	9,614,000

For tubes with longitudinal and cross joints as in ordinary boiler flues:

Experiment.	n.	c.
33	2·34	14,832,000
51	2·41	17,050,000
52	2·39	16,490,000
53	2·34	14,666,000
54	2·33	14,697,000
Means . . .	2·35	15,547,000

The agreement of the constants in this last case is very satisfactory.

Hence, inserting these values, the formulæ for collapse are as follows:—

For tubes with a longitudinal lap joint,

$$p = 7{,}363{,}000 \frac{t^{2\cdot 1}}{l^{0\cdot 9}\, d^{1\cdot 16}} \quad . \quad . \quad . \quad . \quad (22)$$

For tubes with a longitudinal butt joint,

$$p = 9{,}614{,}000 \frac{t^{2\cdot 21}}{l^{0\cdot 9}\, d^{1\cdot 16}} \quad . \quad . \quad . \quad . \quad (23)$$

For ordinary boiler flues with longitudinal and cross joints,

$$p = 15{,}547{,}000 \frac{t^{2\cdot 35}}{l^{0\cdot 9}\, d^{1\cdot 16}} \quad . \quad . \quad . \quad . \quad (24)$$

The formulæ become in a logarithmic form suitable for arithmetical calculation,

$$\log. p = 6\cdot 8671 + 2\cdot 1 \ \log. t - 0\cdot 9 \log. l - 1\cdot 16 \log. d.$$
$$\log. p = 6\cdot 9829 + 2\cdot 21 \log. t - 0\cdot 9 \log. l - 1\cdot 16 \log. d.$$
$$\log. p = 7\cdot 1916 + 2\cdot 35 \log. t - 0\cdot 9 \log. l - 1\cdot 16 \log. d.$$

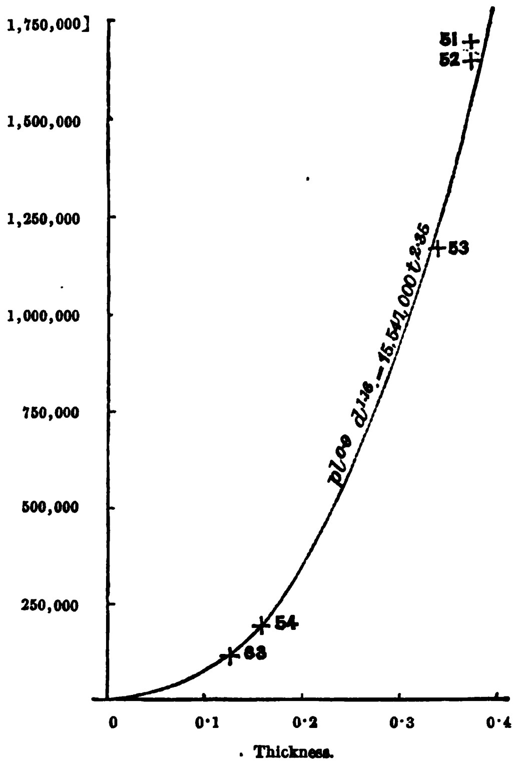
It is not necessary for practical purposes to use more than four decimal places of the logarithms.

It will be seen that the indices of the thickness do not differ more

than would be anticipated from Hodgkinson's value. It is believed that the separation of the experiments, here adopted, into sets of similar experiments, leads to more reliable results than the mixing up of heterogeneous experiments to obtain average values of the constants.

In applying these formulæ to practical cases, it ought to be borne in mind, that slight deviations from the circular form may greatly affect the value of λ, and much reduce the strength of the flue. Hence it seems reasonable that a higher factor of safety should be adopted for flues which are liable to loss of strength from deterioration of form, than for the shells of boilers which are not subject to any such liability.

FIG. 2.



EXPERIMENTS ON ORDINARY FLUES WITH LONGITUDINAL AND CROSS JOINTS.

The above diagram (Fig. 2) shows the accordance with the formula of the experiments on tubes having both longitudinal and cross

joints. The abscissæ of the curve are values of the thickness, and its ordinates are values of 15,547,000 $t^{2\cdot35}$. The numbered crosses are set off with abscissæ equal to the values of the thickness in experiments 33, 54, 53, 52, and 51; and with abscissæ equal to values of $p\ l^{0\cdot9}\ d^{1\cdot16}$, calculated from the experimental values of p, l, and d.

The following table exhibits the comparison in another form:—

No. of Experiment.	Observed Collapsing Pressure.	Collapsing Pressure calculated by formula (24).	Collapsing Pressure calculated by Fairbairn's formula (1).
33	125	131·1	116·0
51	97	88·4	64·0
52	127	119·8	89·6
53	99	104·9	75·5
54	110	116·3	77·2

It will be seen that formula (24) agrees much more closely with the experimental results than Fairbairn's formula (1). The reason is that in obtaining Fairbairn's formula the experiments on thin tubes have an undue weight.

As the formula in this Paper is not convenient for arithmetical calculations, let

$$p = 15{,}547{,}000 \frac{t^2}{l\,d} \cdot \frac{\alpha}{\beta\,\gamma} \quad . \quad . \quad . \quad . \quad (25)$$

Then if the following values are given to the variable co-efficients α, β and γ, the collapsing pressure is found approximately by a simple calculation, and logarithms may be dispensed with.

When t lies between	0·061 and 0·087	0·087 and 0·119	0·119 and 0·159	0·159 and 0·206	0·206 and 0·261	0·261 and 0·325	0·325 and 0·399	..
α = . .	0·40	0·45	0·50	0·55	0·60	0·65	0·70	..
When t lies between	0·399 and 0·483	0·483 and 0·577	0·577 and 0·682	0·682 and 0·800	0·800 and 0·931	0·931 and 1·07	..	..
α = . .	0·75	0·80	0·85	0·90	0·95	1·00	..	..
When l lies between	13 and 25	25 and 51	51 and 110	110 and 253	253 and 628	..	..	..
β = . .	0·75	0·70	0·65	0·60	0·55	..	..	..
When d lies between	2·4 and 4·0	4·0 and 6·5	6·5 and 10·2	10·2 and 15·5	15·5 and 22·9	22·9 and 33·0	33·0 and 47·0	47 and 65
γ = . .	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9

"Engineering" for May 26, 1875,[1] records an experiment on the collapse of a flue of exceptional dimensions, made by the Engineer-in-Chief of the United States Navy at Washington. The flue was 4 feet 6 inches in diameter, 6 feet long, and was divided by a ring into equal lengths of 3 feet. The plates were $\frac{1}{4}$ inch thick. This flue had butt joints, but apparently no cross joints. When subjected to pressure one length began to bulge at 100 lbs. The bulge was shored up, and on repeating the experiment, new bulges began to form at 130 lbs. pressure in the same part of the tube. When these were shored up the other part of the tube began to give way at 128 lbs. Hence the collapsing pressure must have been at least $\frac{1}{3}(100 + 130 + 128) = 120$ lbs., and it probably was higher because only a slight amount of bulging was obtained in the experiments. Now by Fairbairn's rule the collapsing pressure of this flue should have been 239 lbs. By the new rule for tubes with butt joints, and no cross joints, the collapsing pressure should have been 175 lbs., which latter result agrees best with what was observed. It is probable that a flue so large and thin was not perfectly cylindrical.

[1] *Vide* "Engineering," vol. xxi., p. 441.

No. 1,486.—"The Evaporative Performance of Steam Boilers." By D. KINNEAR CLARK, M. Inst. C.E.

MR. GRAHAM'S EXPERIMENTS, 1858.

Mr. John Graham published, in 1858,[1] an account of his experiments on the proportional evaporative value of the heating surfaces of boilers.

1st Series.—Four open tin pans, 12 inches square, in a row, were set in brickwork. From a grate, 12 inches square, placed directly under the first pan, and 9 inches below it, a flash-flue, 3 inches deep, conducted the gaseous products under the other pans towards a chimney. The first pan showed "the direct heating effect of fire;" the second, the effect of an "equal surface of blaze;" the third and fourth, the effect of heated air only. With a "moderately strong draft," the quantities of water evaporated per hour were proportionally :—

		Percentage of Evaporative Duty.
1st pan	as 100	67·6
2nd "	" 27	18·2
3rd "	" 13	8·8
4th "	" 8	5·4
		100·0

Thus two-thirds of the whole evaporation was effected from the first pan, and only a twentieth from the last pan.

2nd Series.—Three cylinders of ¼-inch plate, 3 feet in diameter and 3 feet long, open to the atmosphere, in a row end to end, were set in brickwork. A grate, 3 feet long and 2 feet wide, was placed 9½ inches below the first cylinder, with a flash-flue under the second and third cylinders, concentric with them, of 4 inches radial width, and carried up on each side to the level of the centre of the cylinders.

The average results of eleven trials for evaporations, with the calculated heating surfaces, were as follows :—

	Square feet.
Area of grate	6·00
Heating surface of 1st cylinder	10·53
" " 2nd "	14·13
" " 3rd "	14·13
Total heating surface	38·79

[1] *Vide* Transactions of the Literary and Philosophical Society of Manchester, vol. xv., 1858.

The amount of Worsley coal consumed was 72 lbs. per hour, or 12 lbs. per square foot of heating surface per hour. At 60° Fahr., 4·55 lbs. of water were evaporated per lb. of coal; and the duty was proportionately:—

		Percentage of Duty.	
		For whole surface.	Per sq. foot.
1st pan	as 100·0	66·4	73·0
2nd „	„ 34·7	23·0	18·5
3rd „	„ 16·0	10·6	8·5
		100·0	100·0

showing that about three-fourths of the evaporative work per square foot of surface was done by the first cylinder, and only one-twelfth by the third cylinder.

Experiments of Mr. E. Woods and Mr. J. Dewrance, 1842.

Successive portions of the flue-tubes of a locomotive-boiler, 5 feet 6 inches long, were divided into six compartments by vertical diaphragms. The first compartment was 6 inches long, and each of the others 12 inches. It was found that the evaporative duty of the first compartment was nearly the same per square foot as that of the fire-box; that of the second compartment about a third of that value; that of the remaining compartments very small; and that the first 6 inches did more work than the remaining 60 inches of tube.[1]

Mr. D. K. Clark's Experiments, 1852.

The Author, in 1852,[2] deduced, from a large number of experiments and observations made by himself and by others on locomotive-boilers using coke, that, assuming throughout a constant efficiency of the fuel, or proportion of water evaporated to the fuel, the evaporative performance of a locomotive-boiler, or the quantity of water which it was capable of evaporating per hour, *decreases* directly as the grate-area is increased: that is to say, the larger the grate the smaller is the evaporation of water, at the same rate of efficiency of fuel, even with the same heating surface. 2nd, That the evaporative performance *increases* directly as the square of the heating surface, with the same area of grate, and efficiency

[1] *Vide* "The Engineer," March 1858.

[2] *Vide* "Railway Machinery, 1852," p. 159. See also a Paper on "Locomotive Engine Boilers," by the Author, in the Minutes of Proceedings Inst. C.E., vol. xii., 1852–53.

of fuel. 3rd, The necessary heating surface *increases* directly as the square root of the performance; that is to say, for example, for four times the performance or water evaporated, with the same efficiency, twice the heating surface only is required. 4th, The necessary heating surface *increases* directly as the square root of the grate, with the same efficiency: that is to say, for instance, if the grate be enlarged to four times its first area, twice the heating surface would be required for the same evaporative performance, with the same efficiency of fuel.

Let W be the quantity of water evaporated per hour, and C the weight of coke consumed per hour, W and C varying so as to preserve a constant ratio to each other; let h = the heating surface, and g = the area of grate in square feet; then

$$W = m\frac{h^2}{g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which m is a constant. When the water, W, is expressed in cubic feet, and 9 lbs. of water are evaporated per lb. of fuel, the value of m, deduced from the results of forty experiments, was ·00222; and

$$W = \cdot 00222\frac{h^2}{g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Reduced to the standard of 1 square foot of grate, let w and c be the weights of the coal and the water respectively per square foot of grate, in constant ratio to each other; then, dividing the above formulæ respectively by g,

$$w = m\left(\frac{h}{g}\right)^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and $$w\text{ (cubic feet)} = \cdot 00222\left(\frac{h}{g}\right)^2. \quad . \quad . \quad . \quad . \quad (4)$$

showing that, when the ratio of the water to the fuel, or the efficiency of the fuel, is constant, the performance of the boiler per square foot of grate increases as the square of the ratio of the heating surface to the grate-area; or, in brief, as the square of the surface-ratio.

The following table of examples, extracted from "Railway Machinery,"[1] shows how closely the evaporation proceeded according to the square of the surface-ratio, when 9 lbs. of water, at the ordinary temperatures and pressures, were evaporated per lb. of coke.

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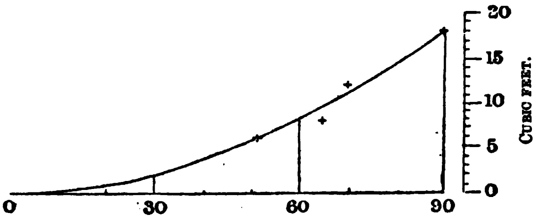
[1] "Railway Machinery," p. 158.

TABLE 1.—RELATIVE HEATING SURFACES and RATES of CONSUMPTION of WATER in LOCOMOTIVE-BOILERS.

Classified Groups of Locomotives.	Surface-ratio.	Consumption of Water per hour per square foot of Grate.	Water per lb. of Coke.	Number of Experiments.
	Ratio.	Cubic feet.	lbs.	
Orion, Sirius, Pallas, E. & G. Ry.	52	6·15	9·0	13
C. R. Passenger Engines . .	66	8·0	9·1	17
Snake, L. & S. W. Ry. . .	72	12·0	8·9	2
Sphynx, A, Hercules . . .	90	18·0	8·92	8

The quantities of water are thrown into the parabolic curve, Fig 1, as ordinates to the base-line, on which the relative quantities of coke consumed per square foot of grate are measured.

FIG. 1.



LOCOMOTIVE-BOILERS.—Diagram to show the rate of Economical Consumption of Water per square foot of grate per hour, for given surface-ratios.

It was thus found that, practically, there can never be too much heating surface as regards economical evaporation, but there may be too little; and that, on the contrary, there may be too much grate-area for economical evaporation, but there cannot be too little, so long as the required rate of combustion per square foot does not exceed the limits imposed by physical conditions.

EXPERIMENTAL DEDUCTIONS OF M. PAUL HAVREZ, 1874.

That the evaporative performance of similar boilers per unit of grate-area increases with the square of the surface-ratio, is confirmed by the deduction by M. Paul Havrez of the following law,

from the performances of locomotive boilers[1]:—That the quantities of water evaporated by consecutive equal lengths of flue-tubes decrease in geometrical progression, whilst the distances from the commencement of the series increase in arithmetical progression. The point, he adds, at which the law begins to prevail, is that at which the radiation of heat from the fuel ceases, and heat is communicated by conduction alone. One of the experiments, of which the results were investigated by M. Havrez, was made by M. Pétiet, of the Northern Railway of France, who repeated the experiment of Mr. Woods and Mr. Dewrance, and tested the evaporative value of the different parts of a locomotive-boiler, having tubes of a length of 12 feet 3 inches, divided into five compartments. The first compartment consisted of the fire-box, with 3 inches of length of the tubes; the four tube sections were 3·02 feet long. Using coke and briquettes as fuel, the average results were as follows:—

—	Fire-box Section.	1st Tube Section.	2nd Tube Section.	3rd Tube Section.	4th Tube Section.
Surface	60·28 box. 16·15 tubes. 76·43	179	179	179	179 sq. ft.
Water evaporated per square foot per hour with coke . . .	24·5	8·72	4·42	2·52	1·68 lbs.
Do. do. with briquettes	36·9	11·44	5·72	3·52	2·31 „

M. Havrez's law of progression is traceable here; and whether it be exact or only approximately true, the rapidly diminishing evaporations are corroborative of the results of previous experiments.

If the successive evaporations be set off as ordinates to a base-line representing the advance of the heating surface, and contoured, the area of the figure is a measure of the total evaporation. The area would bulk largely at the first part, whence it would fall rapidly, and taper more slowly towards the end; and it is easily comprehended that such areas of evaporation, for boilers of different total lengths or quantities of surface, would increase practically as the squares of the total surfaces, supposing that the final temperatures of the gases on leaving the boilers were the same.

[1] "Evaporation in Steam Boilers decreasing in Geometrical Progression," by M. Paul Havrez, "Annales du Génie Civil," August and September 1874; abstracted in the Minutes of Proceedings Inst. C.E., vol. xxxix., p. 378, 1874–75.

General Relations of Grate-area, Heating Surface, Water, and Fuel.

It is well known that, in a given boiler in which the grate and the heating surface are constant—and, of course, also the ratio of the surface to the grate-area—the greater the quantity of fuel consumed per hour, the greater also is the quantity of water evaporated; but that the production of steam increases at a less rate than the combustion: in other words, that the quantity of water evaporated per lb. of fuel is diminished. But it has remained a question—at what rate does this diminution of efficiency take place? The answer is supplied by the fact, generalised from experimental observations on stationary, portable, marine, and locomotive boilers, that the quantity of water evaporated per square foot of grate is expressed by a constant quantity, A, plus a constant multiple, B c, of the fuel consumed per square foot of grate; or by the general formula

$$w = \mathrm{A} + \mathrm{B}\,c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The sense of this equation is that, though the proportion of the water evaporated per square foot of grate does not keep pace with the fuel consumed, yet that the quantity of water increases by equal increments for equal increments of fuel per square foot of grate.

To co-relate this formula (5), in which the surface-ratio is constant, with the formula (4), in which the evaporative efficiency of fuel is constant, it may suffice for the present to observe that the quantity B c is constant for all surface-ratios, and that the quantity A varies as the square of the surface-ratio. Let the surface-ratio $\frac{h}{g} = r$, then $\mathrm{A} = ar^2$, in which a is a constant which is specific for each kind of boiler; and

$$w = ar^2 + \mathrm{B}\,c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

w = the water evaporated in lbs. per square foot of grate per hour;

c = the fuel consumed in lbs. per foot of grate per hour;

$\mathrm{E} = \frac{w}{c}$, the efficiency of the fuel, or the weight of water evaporated per lb. of fuel;

$\mathrm{A} = ar^2$ = a constant, specific for each boiler;

B = a constant multiplier, specific for each kind of boiler;

$r = \frac{h}{g}$ = the ratio of the heating surface to the grate-area; or the surface-ratio;

a = a constant, specific for each kind of boiler.

When the consumption of water and fuel per square foot of grate per hour is given, the value of the required surface-ratio is found from the above formula, for $ar^2 = w - Bc$, and

$$r = \sqrt{\frac{w - Bc}{a}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

When the consumption of water per square foot of grate per hour, and the surface-ratio, are given; to find the amount of fuel per square foot of grate per hour required to evaporate the water: $Bc = w - ar^2$, and

$$c = \frac{w - ar^2}{B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

When the efficiency, $E, = \frac{w}{c}$, of the fuel is given—that is, the weight of water evaporated per lb. of fuel—also the surface-ratio; to find the fuel that may be consumed per square foot of grate per hour corresponding to that efficiency. As $\frac{w}{c} = E = \frac{ar^2 + Bc}{c} = B + \frac{ar^2}{c}$; then $ar^2 = c\,(E - B)$; and

$$c = \frac{ar^2}{E - B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

When the efficiency, $E, = \frac{w}{c}$, and the fuel consumed per square foot of grate per hour, are given; to find the surface-ratio required to effect that evaporation. Since $ar^2 = c\,(E - B)$, and $r^2 = \frac{c\,(E - B)}{a}$,

$$r = \sqrt{\frac{c\,(E - B)}{a}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Evaporative Performance of Newcastle Coals in an Experimental Marine Boiler at Newcastle-on-Tyne, 1857.[1]

These experiments were made to test the evaporative power of the steam-coal of the Hartley district of Northumberland. The

[1] The Author has derived the particulars of these trials from the Reports of Messrs. Longridge, Armstrong, and Richardson to the Steam Collieries Association of Newcastle-on-Tyne, 1857.

experimental boiler was of the marine type, 10 feet 3 inches long, 7 feet 6 inches wide, and 10 feet high, with two internal furnaces 3 feet by 3 feet 3 inches high, and one hundred and thirty-five flue-tubes above the furnaces, in nine rows of fifteen each, 3 inches in diameter inside, 5½ feet long. The dead-plates were 16 inches deep, and 21 inches below the crown of the furnace. As the result of many preliminary trials, two standard lengths of fire-grates were fixed upon—4 feet 9 inches, and 3 feet 2½ inches, with a fall of ½ inch to a foot; and the fire-bars were cast ½ inch thick, with air-spaces from ⅝ to ¾ inch wide. The fire-doors were made with slits, ½ inch wide and 14 inches long, for the admission of air. The chimney was 2 feet 6 inches in diameter. A water-heater was applied at the base of the chimney, in the thoroughfare; it contained seventy-six vertical tubes, 4 inches in diameter, surrounded by the feed-water.

	Square feet.
Total area of fire-grates, 4 feet 9 inches long	28½
„ „ 3 „ 2½ „	19¼
Heating surface of boiler, outside	749
„ „ water-heater	320
Ratio of larger grate-area to the heating surface of boiler	1 to 26·28
„ smaller „ „ „ „ .	1 to 38·91

Two systems of firing were adopted as "standards of practice." First, ordinary or spreading firing, in which the fuel was charged over the grate, and the air was admitted through the grate. Second, coking firing, in which the fuel was charged, 1 cwt. at a time, upon the dead-plate, and subsequently pushed on to the grate, making room for the next charge, and air was admitted by the doorway as well as by the grate. Four systems of furnace were used, of which Mr. C. W. Williams's was adjudged to have rendered the best performance. According to this system, air was admitted above the fire, at the front of the furnace, by means of cast-iron casings having apertures on the outside, with slides, and perforated through the inner face, next the fire, with numerous ⅝-inch and ½-inch holes, having a total area of 80 square inches, or 5·33 square inches per square foot of grate. Alternate firing was adopted by Mr. Williams.

The general results of the experiments are given in Table No. 2. (See next page.)

TABLE 2.—EVAPORATIVE PERFORMANCE of NEWCASTLE COALS (of the HARTLEY DISTRICT of NORTHUMBERLAND) in an EXPERIMENTAL MARINE BOILER at NEWCASTLE-UPON-TYNE, 1857.

(Compiled from the Report of Messrs. Longridge, Armstrong, and Richardson to the Steam Collieries Association of Newcastle-on-Tyne.)

Numerical Order.	1 Plan of Furnace.	2 Area of Fire-grate.	3 Coal consumed per hour.	4 Coal per square foot of Grate per hour.	5 Water consumed from 60° Fahr. per hour.	6 Water per square foot of Grate per hour.	7 Water evaporated as from 212° per lb. of Coal.	Remarks on the prevention of Smoke, &c.
		Sq. feet.	Cwt.	lbs.	Cub. feet.	Cub. feet.	lbs.	
1	Standard grate, ordinary management	28·5	5·38	21·15	74·80	2·62	8·94	Air admitted entirely through the grate. Much smoke, often very dense.
2	„ best „	,,	4·88	19·00	79·12	2·93	11·13	Air admitted through both the grate and the door. No smoke.
3	„ ordinary „	19·25	3·61	21·00	56·01	2·91	10·00	Air through the grate alone; used 100 cubic feet per lb. of coal; temperature in uptake 448°. Much smoke.
4	„ best „	,,	3·00	17·25	57·78	2·995	12·53	Air through the grate and the door. Used 70 cubic feet through the grate, and 88 cubic feet through the doors, per lb. of coal. Temperature in uptake 480°. No smoke.
5	C. W. Williams's plan	22·0	3·33	17·27	61·59	2·84	11·70	Prevention of smoke practically perfect.
6	„ „	,,	5·30	26·98	86·96	4·04	10·80	„ „
7	„ „	18·0	4·40	27·36	76·92	4·31	11·37	„ „
8	„ „	15·5	5·18	37·40	85·30	5·51	10·63	Prevention of smoke practically perfect. Temperature at base of chimney above 600°.

NOTES TO TABLE.—1. When the temperature was 600° in the uptake of the boiler, it was reduced by from 40° to 50° after having passed through the water-heater.

2. In another case, working with Williams's apparatus, no air was admitted through the door; and, with much smoke, the temperature in the uptake was 600°. With one aperture in the door opened it was raised to 625°, with two apertures 633°, with three 638°, with five it fell to 620°.

3. The quantities in column 7 have been recalculated.—D. K. C.

TRIAL OF NEWCASTLE AND WELSH COALS AT NEWCASTLE FOR THE BOARD OF ADMIRALTY. BY MESSRS. MILLER AND TAPLIN. 1858.

Messrs. Miller and Taplin, representing the Board of Admiralty, conducted, in 1858, a series of trials at Newcastle, with the same marine boiler as was employed by Messrs. Longridge, Armstrong, and Richardson, the object of which was to investigate the comparative evaporative power and other properties of Hartley coal and Welsh steam-coal, and the merits of Mr. Williams's plan of smoke-prevention.

The fire-bars were $1\frac{1}{4}$ inch thick, and had $\frac{5}{8}$-inch air-spaces. The feed-water was passed through the heater, except when otherwise stated. Mr. Williams's apparatus was constantly in action when Hartley coal was burned, without smoke, and it was closed when this coal was tried for smoke-making, also when Welsh coal was burned.

During the trials of Hartley coal, the fires were maintained at from 12 to 14 inches in thickness on the grates; the coal was stoked on the coking system, the fresh charges of coal having been delivered at the front on each side of each grate alternately, and the incandescent fuel pushed forward towards the bridge, before charging.

In the trials of Welsh coal, the fires were maintained at from 8 to 10 inches in thickness; and in charging, the fresh coal was thrown where it was required, all over the fire, the burning fuel never having been touched by any firing tool. The cinders that fell through the grates were constantly raked together and thrown upon the fires.

The results of the trials made by Messrs. Miller and Taplin have been analysed and compiled into the Table No. 3, in which the results of the performance of the West Hartley coals are grouped, to which is added those obtained from Lambton's Walls-end house coal as a bituminous or highly smoky coal. Similar information respecting the Welsh coal is likewise grouped. Separate trials of each coal were made in which the feed-water was delivered direct into the boiler, the heater having been for this purpose disconnected.

TABLE 3.—EVAPORATIVE PERFORMANCE of NEWCASTLE and WELSH COALS, in the same MARINE BOILER as for TABLE 2, with C. W. WILLIAMS'S APPARATUS for the PREVENTION of SMOKE. 1858.

(Compiled from the Report of Messrs. Miller and Taplin to the Board of Admiralty.)

Numerical Order.	1 Coal.	2 Area of Fire-grate.	3 Coal consumed per hour.	4 Coal per square foot of Grate per hour.	5 Water consumed from 60° per hour.	6 Water per square foot of Grate per hour.	7 Water evaporated from 212° per lb. of coal.	Remarks on the prevention of Smoke, &c.
	NEWCASTLE.	Sq. feet.	Cwt.	lbs.	Cub. feet.	Cub. feet.	lbs.	
10	West Hartley, direct from collieries .	42	6·0	16·00	89·84	2·14	9·65	Long grates. Air-passages fully open. No smoke.
11	" " .	,,	6·6	17·60	93·77	2·23	9·14	" " "
12	" " .	,,	6·8	18·13	94·46	2·25	8·96	" " "
13	" " .	33	6·0	20·36	86·24	2·61	9·25	" " "
14	" " .	22	4·34	22·08	76·77	3·49	11·41	Fire heavily charged at intervals to test apparatus. No smoke. Maximum rate of consumption $55\frac{1}{2}$ lbs. per square foot.
15	" " .	,,	4·53	23·04	74·74	3·39	10·62	No smoke.
16	" " .	,,	5·1	25·97	88·43	4·02	11·17	"
17	" " .	,,	5·12	26·05	81·98	3·73	10·33	"
18	" " .	,,	5·6	28·51	92·00	4·18	10·58	"
19	" " .	,,	5·8	29·53	86·63	3·94	9·63	Air-passage above the fuel closed. Dense black smoke.
20	" " (small)	,,	3·4	17·31	55·20	2·51	10·47	No smoke. Trial of small broken coal.
21	" " .	18	3·0	18·67	51·97	2·89	11·17	Trial with slow combustion. Damper in chimney closed to an area of 250 square inches. Grate raised 5 inches. Bars $\frac{5}{8}$ inch thick, spaces $\frac{1}{2}$ inch. No smoke.
22	" " .	,,	4·0	24·89	68·09	3·78	10·96	No smoke.
23	Buddle's West Hartley, direct from collieries	22	5·4	27·49	88·33	3·79	9·95	These trials were made to compare the efficiency of coal brought direct from the collieries with that of the same coal after having been carried about and transhipped. But there was a doubt whether the coal from the dockyard was Buddle's, or another quality.
24	" " from Woolwich Dockyard	,,	4·6	23·42	71·93	3·27	10·08	
25	" " " .	,,	4·6	23·42	77·40	3·52	10·85	
26	" " " .	,,	4·7	24·00	73·73	3·35	10·07	
27	Lambton's Wallsend house coals, direct from colliery	,,	3·2	16·29	59·64	2·71	12·01	Test for bituminous or highly smoky coal. No smoke.

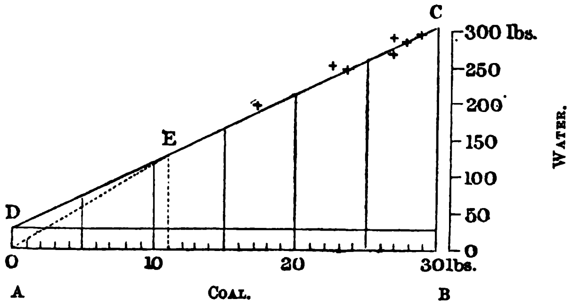
	Newcastle Coal, when the feed-water was passed directly into the boiler, without the heater.							
28	West Hartley	22	5·29	26·92	84·31	3·83	10·27	No smoke.
29	"	,,	5·30	26·98	82·21	3·73	9·98	"
30	"	,,	7·0	35·64	102·76	4·67	9·46	" Forced draught by steam jet in chimney.
31	"	,,	6·2	31·56	78·78	3·58	8·19	Air-passages above fire closed. Dense black smoke.
	South Welsh Coal, with the heater in action. Air-passages above the grate closed, with Welsh coal.							
32	Blaengwarn Merthyr	22	3·6	18·33	69·54	3·16	12·44	No smoke, except very light smoke when firing.
33	Powell's Duffryn	,,	4·06	20·65	79·34	3·60	12·58	" "
34	Welsh coal	,,	4·1	20·87	72·74	3·31	11·44	" "
35	Sent from Woolwich Dockyard	,,	4·3	21·89	77·26	3·51	11·57	" "
36	Welsh coal	,,	4·4	22·40	88·35	4·02	12·95	" "
37	Powell's Duffryn (small)	,,	1·8	9·16	30·43	1·38	10·87	" Trial of the small coal to which the pieces are reduced by exposure to weather, or by being kept in store some time.
38	"	18	3·87	24·12	66·72	3·71	11·10	No smoke, except very light when firing.
	Welsh Coal, when the feed-water was passed directly into the boiler, without the heater.							
39	Blaengwarn Merthyr, sent from Woolwich Dockyard	22	4·55	23·18	74·35	3·38	10·11	No smoke, except light brown when firing.

Note.—The quantities in column 7 have been recalculated.

Deductions from the Experimental Results with the Newcastle Marine Boiler.

Select for comparison from Tables Nos. 2 and 3, the performance of this boiler, with a grate-area of 22 square feet, and 749 square feet of heating surface, 34·05 times that of the grate, with increasing rates of combustion of coal per square foot. Find the corresponding weights of water evaporated per square foot, and plot them to a vertical scale upon a base-line A B, Fig. 2, measuring the

Fig. 2.



Newcastle Marine Boiler:—Diagram to show relation of water and coal per square foot of grate. Area, 22 square feet; constant surface-ratio, 34·05.

weight of coal consumed. They are found to lie in or close to a straight line, C D, drawn obliquely upwards from a point, C, in the ordinate of zero, at a level which is 25 lbs. above the base-line, and the general formula (5) becomes

$$w = 25 + 9 \cdot 71c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

in which A = 25, and B = 9·71. The correspondence of the actual quantities of water evaporated with those which are calculated by this formula from the coal consumed (11),[1] is shown in Table No. 4.

Since $A = ar^2 = 25$ in the present instance; $a = \frac{25}{r^2} = \frac{25}{34 \cdot 05^2} =$ ·02156, and $ar^2 = \cdot 02156r^2$. By substitution, the following formula is obtained, which applies to all surface-ratios in the Newcastle type of boiler:—

$$w = \cdot 02156r^2 + 9 \cdot 71c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

[1] The diagonal line in Fig. 2 does not exactly strike the average of the results for the grate of 22 square feet alone. But it is the average for the results attained from the various sizes of grate taken together.

TABLE 4.—NEWCASTLE MARINE BOILER. RELATIONS of COAL and WATER.
Grate, 22 square feet; surface-ratio, 34·05.

Number of Experiment in Tables Nos. 2 and 3.	Coal per foot of Grate per hour.	Water per lb. of Coal from and at 212° Fahr.	Total Water per foot of Grate per hour. Observed.	By formula (11).	Difference by formula.	Water per lb. of Coal according to formula.
	lbs.	lbs.	lbs.	lbs.	Per cent.	lbs.
5	17·27	11·70	202·0	192·7	− 4·6	11·16
14	22·08	11·41	251·9	239·4	− 5·0	10·84
15	23·04	10·62	244·7	248·7	+ 1·6	10·79
16	25·97	11·17	290·1	277·2	− 4·4	10·67
17	26·05	10·33	269·1	277·9	+ 3·3	10·67
6	26·98	10·80	291·4	287·0	− 1·5	10·64
18	28·51	10·58	301·6	301·8	0·0	10·58

The results of the other experiments with the Newcastle boiler, made with different areas of grate, may be reduced for comparison with those made with the 22-feet grate, by reducing both the coal and the water per square foot per hour, in the ratio of the squares of the respective surface-ratios, whilst the ratio of the coal and water or the efficiency, remains constant. The annexed table, No. 5,

TABLE 5.—NEWCASTLE MARINE BOILER. RELATIONS of COAL and WATER.
Varying grate-area and surface-ratio. Calculations for normal surface-ratio 34·05, by formula (11).

Number of Experiment.	Grate-area.	Surface-ratio.	Coal per square foot of Grate per hour. Actual.	Reduced in the ratio of the square of the surface-ratios, for normal ratios 34·05.	Water per square foot of Grate per hour for normal surface-ratio 34·05. Reduced in the same ratio as for Coal.	Calculated from col. 5 by formula (11).	Difference by formula.
	Square feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Per cent.
10	42·00	17·83	16·00	58·35	563·1	591·6	+ 5·1
11	,,	,,	17·60	63·82	583·3	644·7	+10·5
12	,,	,,	18·13	66·12	594·4	667·0	+12·6
13	33·00	22·70	20·36	45·81	423·7	469·8	+10·9
2	28·50	26·28	19·00	31·90	355·0	334·8	− 5·7
5	22·00	34·05	17·27	17·27	202·0	192·7	− 4·6
14	,,	,,	22·08	22·08	251·9	239·4	− 5·0
15	,,	,,	23·04	23·04	244·7	248·7	+ 1·6
16	,,	,,	25·97	25·97	290·1	277·2	− 4·4
17	,,	,,	26·05	26·05	269·1	277·9	+ 3·3
6	,,	,,	26·98	26·98	291·4	287·0	− 1·5
18	,,	,,	28·51	28·51	301·6	301·8	0·0
4	19·25	38·91	17·25	13·21	165·5	153·3	− 7·4
21	18·00	41·61	18·67	12·50	139·7	146·4	+ 4·8
22	,,	,,	24·89	16·67	182·7	186·9	+ 2·3
7	,,	,,	27·36	18·32	208·3	202·9	− 2·6
8	15·50	48·32	37·40	18·57	197·4	205·3	+ 4·0

shows the reduced water (column 6) corresponding to the reduced coal (column 5), for the normal surface-ratio 34·05. In column 7 the reduced waters are given as calculated by the formula (11), and the differences by the formula, which are inconsiderable, are given in the last column.

To demonstrate the applicability of the formula (12) to the calculation of water evaporated from the given ratios, as they are, the annexed table, No. 6, shows, by comparison (columns 5 and 6), the actual and calculated quantities of water evaporated by the coals (column 4) with the ratios in column 3. The percentages of differences are identical with those already exhibited in the previous table.

The consistency of the results of the application of the formula under widely varying proportions of boiler, and varying rates of combustion, affords evidence of the correctness of the principles on which it is based.

TABLE 6.—NEWCASTLE MARINE BOILER. RELATIONS of COAL and WATER.

Varying grate-areas and surface-ratios. Calculations made for the actual ratios by formula (12).

No. of Experiment.	Grate-area.	Surface-ratio.	Coal per square foot of Grate per hour.	Water per square foot of Grate per hour, for the given surface-ratios.		
				Actual as from and at 212° Fahr.	Calculated by formula (12).	Difference by formula.
	Square feet.	Ratio.	lbs.	lbs.	lbs.	Per cent.
10	42·00	17·83	16·00	154·4	162·2	+ 5·1
11	,,	,,	17·60	160·9	177·7	+10·5
12	,,	,,	18·13	162·5	182·8	+12·6
13	33·00	22·70	20·36	188·3	231·5	+10·9
2	28·50	26·28	19·00	211·5	199·4	− 5·7
5	22·00	34·05	17·27	202·0	192·7	− 4·6
14	,,	,,	22·08	251·9	239·4	− 5·0
15	,,	,,	23·04	244·7	248·7	+ 1·6
16	,,	,,	25·97	290·1	277·2	− 4·4
17	,,	,,	26·05	269·1	277·9	+ 3·3
6	,,	,,	26·98	291·4	287·0	− 1·5
18	,,	,,	28·51	301·6	301·8	0·0
4	19·25	38·91	17·25	216·1	200·1	− 7·4
21	18·00	41·61	18·67	208·5	218·6	+ 4·8
22	,,	,,	24·89	272·8	279·0	+ 2·3
7	,,	,,	27·36	311·1	303·0	− 2·6
8	15·50	48·32	37·40	397·6	413·5	+ 4·0

EVAPORATIVE PERFORMANCE OF SOUTH LANCASHIRE COAL IN THREE EXPERIMENTAL STATIONARY BOILERS AT WIGAN. 1866–68.[1]

The coal selected for trial was Hindley Yard coal, from Trafford pit, which ranks with the best coals of the district. Three stationary boilers were selected:—1. An ordinary double-flue Lancashire boiler, 7 feet in diameter and 28 feet long; two flue-tubes, 2 feet 7½ inches in diameter inside, of ⅜-inch plate. 2. Another Lancashire boiler of the same dimensions, but with tubes of $\frac{5}{16}$-inch steel plate. 3. A Galloway or water-tube boiler, 26 feet long and 6 feet 6 inches in diameter, with two furnace-tubes 2 feet 7⅜ inches in diameter, opening into an oval flue, 5 feet wide by 2 feet 6½ inches high, containing twenty-four vertical conical water-tubes. These three boilers were set side by side, on side walls, and with two dampers. The flame passed through the flue-tubes, back under the boiler, then along the sides to the chimney. The chimney was 105 feet high above the floor, octagonal, 6 feet 10 inches wide at the base and 5 feet wide at the top, where the sectional area was 21 square feet.

Total grate-area in each boiler	6 feet long, 31·5 sq. ft.	
„ „ „	4 „ 21·0 „	
	Lancashire.	Galloway.
Heating surface:—In flue tubes	464·34 sq. ft.	431·12 sq. ft.
In external flues . .	303·08 „	288·24 „
Total surface . . .	767·42 „	719·36 „
Ratio of grate-area, 6 feet long, to heating surface	1 to 24·4 „	1 to 22·8 „
„ „ 4 „ „	1 to 36·5 „	1 to 34·3 „
Circuit, or length of heating surface traversed by the draft from the centre of the grate	80 feet	74 feet
Total distance from centre of grate to base of chimney	117 „	101 „
Height of chimney above level of floor . . .	100 feet	
„ „ „ grates . . .	96 feet 9 inches	

The standard fire adopted for trial was 12 inches thick, of round coal, treated on the coking system, with a little air admitted above the grate for a minute or so after charging. The water was evaporated under atmospheric pressure.

[1] The Author is indebted for the particulars of these trials to the South Lancashire and Cheshire Coal Association's "Report on the Boiler and Smoke-prevention Trials conducted at Wigan," 1869. The experiments were conducted, and the report was written, by Mr. Lavington E. Fletcher, Assoc. Inst. C.E.

The data afforded by these typical boilers are specially useful, as they represent classes of boilers in general use in England. The several experimental results, required for the present purpose, are collected in the annexed table, No. 7; the first two results are for flash-drafts, in which the side and bottom flues were cut off, and the gases were conducted direct to the chimney after having passed through the fire-tubes. By plotting the coal and the water reduced according to the square of the surface-ratios, for a uniform ratio of 30, this formula was obtained:—

$$w = 20 + 9 \cdot 56c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

And, in the general form, for various ratios:—

$$w = \cdot 0222r^2 + 9 \cdot 56c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

By the formula (13), the quantities of water in column 7 of the table, were calculated from the reduced coals in column 5.

TABLE 7.—WIGAN STATIONARY BOILERS. RELATIONS of COAL and WATER.

Varying grate-area and surface-ratio. Calculations for surface-ratio 30, by formula (13).

Boiler (without Economiser).	Grate-area.	Surface-ratio.	Coal per square foot of Grate per hour. Actual.	Coal per square foot of Grate per hour. Reduced in the ratio of the squares of the surface-ratios, for ratio 30.	Water per square foot of Grate per hour, for surface-ratio 30. Reduced in the same ratio.	Water per square foot of Grate per hour, for surface-ratio 30. Calculated from col. 5 by formula (13).	Water per square foot of Grate per hour, for surface-ratio 30. Difference by formula.
	Sq. feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Per cent.
Galloway, flue-tubes only	31·5	13·70	18·58	89·10	757·3	871·8	+15·0
Lancashire, flue-tubes only . .	,,	14·74	19·91	82·47	678·8	808·4	+19·0
Galloway, complete	,,	22·8	18·30	31·68	322·9	322·9	0·0
Lancashire and Galloway	,,	23·5	14·00	22·82	230·4	238·2	+ 3·4
Lancashire . . .	,,	24·4	17·26	26·03	271·5	268·8	− 1·0
„ . . .	,,	,,	18·60	28·12	290·2	288·8	− 0·5
„ . . .	,,	,,	19·10	28·87	293·7	296·0	+ 0·8
Lancashire, with water-tubes . . .	,,	25·4	16·71	23·31	251·0	242·8	− 3·3
Galloway . . .	21·0	34·3	21·80	16·68	179·6	179·5	0·0
Lancashire and Galloway	,,	35·5	23·00	16·43	179·2	177·1	− 1·2
Lancashire . . .	,,	36·5	21·50	14·52	158·0	158·8	+ 0·5
„ . . .	,,	,,	22·70	15·33	165·1	166·6	+ 0·9

Evaporative Performance of South Lancashire and Cheshire, Newcastle, and Welsh Coals in an experimental Marine Boiler at Wigan. 1866–68.[1]

The marine boiler was a copy of the test-boiler at Keyham Dockyard. The shell was rectangular, 5 feet wide for two furnaces, 7 feet 8 inches long, and 8 feet 10 inches high. The furnaces were 1 foot 8⅝ inches wide, 2 feet 8⅜ inches high at the front, rising to 3 feet high at the back, and 6 feet deep from the front to the back or tube-plate. There were one hundred and twenty-four flue-tubes, 2¼ inches in diameter inside, and 5 feet long, placed at a pitch of 3⅛ inches from centre to centre. The chimney was 18 inches in diameter, and 52 feet 8 inches high above the boiler, or 59 feet 8 inches above the level of the grates. The proportions of the furnaces which were adopted after many trials were as follows:—dead-plate, 10 inches long, 16 inches below the crown of the furnace; grates, 3 feet long, inclined ¾ inch to 1 foot, bars ½ inch thick, air-spaces ½ inch; bridge built up to a level, 9 inches below the crown, and 9¼ inches above the grate. The fire-doors were fitted with a sliding grid for the admission of air into a perforated box inside the door. In the first instance, there were seven hundred and thirty perforations, giving an area of 33 square inches, or 3·2 inches per square foot of grate. They were afterwards reduced to three hundred and forty-two in number, 16½ square inches in area, or 1·6 inch per foot of grate.

During the preliminary experiments, it was found of advantage to reduce the length of grate from 4 feet to 3 feet, to adopt a blind dead-plate in preference to a perforated one, and to slightly lower the grate. Fires of 6 inches, 9 inches, 12 inches, and 14 inches in thickness were tried; the greater the thickness, the better was the performance. The firing was tried on the spreading and the coking systems.

Coking firing was adopted as the standard method, with fires of 14 inches and 12 inches in thickness. The furnaces were charged alternately, and the entrance for air through the door was allowed to remain open for a few minutes after each charge was delivered, for the prevention of smoke. For each trial, 1,000 lbs. of round coal were consumed, lasting three hours twenty-seven minutes, on an average; the average rate of consumption

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[1] The Author is indebted for the particulars of these trials to Mr. Lavington E. Fletcher's report: see note, p. 257.

was 290 lbs. per hour, or 28 lbs. per square foot of grate per hour. The feed-water was supplied at ordinary temperatures. The steam was generated under 1 atmosphere of pressure, and escaped direct into the air.

Total grate-area		10·3 square feet
Total heating surface :—		
Plate, above the grate . . .	95 square feet	508 "
Tubes, outside surface . . .	413 "	
Ratio of grate-area to heating surface		1 to 50

The average results of the trials selected for the present purpose, are placed in the following table, No. 8, together with the quantities of water evaporated as calculated by the following formula, deduced from the plotting of the results:—

$$w = 25 + 10{\cdot}75c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

showing a smaller constant, and a greater multiple, than the formula of the Newcastle boiler. Substituting for 25 the general expression ar^2, and reducing for the value of a, the general formula is

$$w = {\cdot}01r^2 + 10{\cdot}75c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

which may be employed for different surface-ratios.

TABLE 8.—WIGAN MARINE BOILER. RELATIONS of COAL and WATER.

Grate, 10·3 square feet; surface-ratio, 50.

Description of Coals.	Coal per foot of Grate per hour.	Water per lb. of Coal from and at 212° F.	Total Water per square foot of Grate per hour. Observed.	By formula (15).	Difference by formula.
	lbs.	lbs.	lbs.	lbs.	Per cent.
South Lancashire and Cheshire coals. Mr. Fletcher's trials	27·63	11·54	318·8	322·1	+1·0
South Lancashire and Cheshire coals. Messrs. Nicol and Lynn's trials	27·50	11·92	327·8	320·6	−2·2
	41·25	11·36	468·6	468·6	0·0
Hartley (Newcastle) coals . .	28·83	11·95	344·5	334·9	−2·8
Welsh coals	26·20	12·44	325·9	306·6	−6·0

It appears from this table that the South Lancashire and Cheshire coals, and the Newcastle coals, were equally efficient, and that the Welsh coals had a slightly greater evaporative action than the others.

COMPARATIVE EVAPORATIVE PERFORMANCE OF STATIONARY BOILERS IN FRANCE. 1874.

An abstract of the Report on the trials of boilers of three types—the "Fairbairn," as it was called, the Lancashire, and the French or elephant boiler—has already been published in the Proceedings,[1] to which reference is now made for particulars. The proportions and the results, with Ronchamp coal, are treated in the following table, No. 9. The following special formulæ have been deduced for the three boilers respectively, and for the three collectively:—

"Fairbairn" $w = \cdot 01143r^2 + 7\cdot 7c$ . . (17)
Lancashire $w = \cdot 01126r^2 + 8\cdot 0c$ . . (18)
French $w = \cdot 01126r^2 + 8\cdot 0c$ . . (19)
All the boilers $w = \cdot 0111r^2 + 7\cdot 82c$. . (20)

It is seen that the same formula applies to the Lancashire and the French boilers, and that, therefore, the reporters of the trials were justified in asserting that these boilers were equally efficient.

TABLE 9.—STATIONARY BOILERS in FRANCE. RELATIONS of COAL and WATER.
Calculations of evaporative performance for surface-ratio 30; Ronchamp coal.

Boilers.	Grate-area.	Surface-ratio.	Coal per square foot of Grate per hour.		Water per square foot of Grate per hour for surface-ratio 30.		
			Actual.	Reduced in the ratio of the square of the surface-ratios for ratio 30.	Reduced in the same ratio.	Calculated from column 5 by formulæ (17), (18), (19).	Difference by formula.
	Square feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Per cent.
"Fairbairn"	20·5	49·5	10·70	3·93	34·8	40·70	+17·0
,,	,,	,,	18·53	6·81	62·7	63·30	+ 0·9
Lancashire	,,	29·8	10·41	10·55	94·1	92·50	− 1·7
,,	,,	,,	19·15	19·41	165·0	161·80	− 1·9
,,	,,	,,	19·50	19·76	166·8	164·50	− 1·4
French .	20·1	30·3	11·36	11·14	95·5	9·71	+ 1·7
,, .	,,	,,	19·87	19·48	165·4	162·30	− 1·9
,, .	,,	,,	20·57	20·16	166·6	167·60	+ 0·6

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 377.

The comparatively inferior quantity evaporated in the first trial in the table, resulted probably from an excessively large surplus of air admitted into the furnace. The total quantity of air, in that instance, amounted to 261 cubic feet per lb. of coal.

EVAPORATIVE PERFORMANCE OF LOCOMOTIVE-BOILERS.

The Author has collected from various trustworthy sources, the results of the performance of locomotive-boilers of the earliest as well as the most recent designs.[1] Boilers of nearly every size and variety that have been used in England are represented in the tables. The areas of grate vary from 6 to 24 square feet, the heating surfaces from 40 to 2,000 square feet, and the ratios of surface to grate from 40 to 1, to 100 to 1. The fuel was coke, except in a few instances of boilers designed for burning coal, in which coal was used.

These experimental trials have been conducted under various conditions. There is, nevertheless, a remarkable degree of harmony amongst them; for, when plotted, they are seen, with a few exceptions of early date, to follow the laws of evaporative performance already enunciated. Even the performance of the boiler of the primitive Killingworth engine, when the evaporative efficiency is increased by one-half to represent the value of coke compared with coal as imperfectly burned in that boiler, ranges as well as should have been expected with those of other locomotives; in fact, the improved Killingworth boiler exhibits a performance above the average.

Using good coke as fuel, the evaporative performance of locomotive-boilers, in which the flue-tubes are spaced sufficiently apart to admit of a free circulation of water around them, is substantially embraced by the following formula, when the surface-ratio is 75, which is a good practical ratio:—

$$w = 100 + 7 \cdot 94c \text{ (coke)} \quad . \quad . \quad . \quad . \quad . \quad (21)$$

For any given surface-ratio, the general formula is

$$w = \cdot 0178r^2 + 7 \cdot 94c \text{ (coke)} \quad . \quad . \quad . \quad . \quad (22)$$

Using good coal as fuel—Griff, Staveley, Hartley's, and coking

[1] These data are derived from the Author's work on "Railway Machinery," p. 156, and "Railway Locomotives," p. *33. They also, for the greater part, were exhibited in the "Table of Performances of Locomotives," in the Author's Paper already referred to, vol. xii., p. 390, Minutes of Proceedings Inst. C.E.

coal from Newcastle—the formulæ for the coal-burning locomotive-boilers of the South-Eastern and London and South-Western Railways are:[1]

	S. E. Ry.	L. and S. W. Ry.	
For surface-ratio 75	$w = 50 + 9 \cdot 6c$	$w = 50 + 9 \cdot 82c$	. (23)
„ any surface-ratio	$w = \cdot 009r^2 + 9 \cdot 6c$	$w = \cdot 009r^2 + 9 \cdot 82c$	(24)

Evaporative Performance of Portable Steam-engine Boilers. 1872.

The results of the excellently-conducted trials of portable steam-engines exhibited at the Show of the Royal Agricultural Society at Cardiff, in 1872, were fully reported by the Judges, Mr. F. J. Bramwell and Mr. Menelaus.[2] To this valuable Report, with the tables appended to it, prepared by the Consulting Engineers, Messrs. Eastons and Anderson, the Author is indebted for the data with which he has formed Table No. 10 (see next page). The fuel was Llangennech (Welsh) coal. The average quantity of ash and clinker was, as far as it was observed, about 6 per cent. of the fuel. The boilers were of the ordinary pattern, having a fire-box and multitubular flues; but Messrs. Davey, Paxman, and Co.'s boiler contained, in addition, ten circulating wrought-iron bent water-tubes, $2\frac{1}{4}$ inches in diameter in the fire-box, rising from the sides to the top.

These boilers are arranged in the annexed table, No. 11, in the order of the surface-ratios. The coal and the water per square foot of grate are reduced for the ratio 50 (columns 5, 6), from which has been deduced, by plotting, the formula

$$w = 20 + 8 \cdot 6c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

For any given surface-ratio the general formula is

$$w = \cdot 008r^2 + 8 \cdot 6c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

The calculated quantities of water (column 7) by formula (25) follow closely the reduced quantities (column 6), except in the first three instances, Nos. 12, 1, and 8, where they are much in excess. In these instances, the excessive reduction of the grate has involved a material departure from the normal disposition of a

[1] For the data on which the formulæ for coal-burning locomotives are based, see the Author's Paper "On the Improvement of Railway Locomotive Stock, and the Reduction of the Working Expenses," Minutes of Proceedings Inst. C.E., vol. xvi., p. 3; also "Railway Locomotives," pp. *33, *35.

[2] The Trials of Portable Steam-engines at Cardiff. Report by the Judges. 1872.

TABLE 10.—PORTABLE STEAM-ENGINE BOILERS. PROPORTIONS and RESULTS of EVAPORATIVE PERFORMANCE, 1872.

(Compiled and reduced from the Report of the Judges, Royal Agricultural Society's Show, Cardiff.)

Fuel: Llangennech (Welsh) Coal.

No.	Constructors.	Area of Fire-grate.		Heating Surface (Tubes measured on outside).	Ratio of Heating Surface to Trial Fire-grate.	Coal consumed per square foot of Grate per hour.	Equivalent Water evaporated from and at 212° Fahr. per square foot of Grate per hour.		Equivalent Water evaporated per lb. of Coal.
		Normal.	As reduced for Trial.						
		Square feet.	Square feet.	Square feet.	Ratio.	lbs.	lbs.	Cubic feet.	lbs.
1	Marshall, Sons, and Co.	4·4	3·0	283·5	94·5	15·7	161	2·58	10·23
2	Clayton and Shuttleworth . . .	5·3	3·2	220·0	69	12·8	151	2·42	11·83
	"	,,	,,	,,	,,	12·5	148	2·36	11·81
3	Hayes	5·1	5·1	170·6	33	14·8	66·5	1·06	4·59
4	Davey, Paxman, and Co.. . . .	3·75	3·75	168·4	45	10·3	114	1·83	11·02
5	Tuxford and Sons.	6 13	..	193·0	..	..	..	..	..
6	Brown and May	3·2	3·2	159·1	50	9·53	104	1·66	10·89
7	Tasker and Sons	4·7	4·7	158·0	34	13·0	119	1·91	9·33
8	Reading Iron Works	7·2	2·37	211·0	89	20·4	214	3·43	10·49
9	Lewin	4·3	1·6	151·6	..	..	..	..	..
10	E. R. and F. Turner	3 5	3·5	187·8	54	20·7	204	3·26	9·93
11	Barrows and Stewart	5·0	5·0	129·8	26	13·6	120	1·93	8·97
12	Ashby, Jeffery, and Luke. . . .	5·5	2·0	204·5	102	31·1	319	5·10	9·27

fire-box, especially for No. 8, in which the grate was reduced to a third of its normal area, and the surface-ratios were driven up to 102, 94·5, and 89; and the first two boilers, Nos. 12 and 1, have the greatest number and the smallest diameters of tubes. The drift of the evidence goes to show that fewer tubes, of larger diameter, do better for the combustion of coal, the circulation of water, and the absorption of heat.

There is another exceptional boiler, No. 3, with a surface-ratio 33, in which the calculated quantity of water is twice as much as the reduced actual quantity. The excess, in this case, is satisfactorily accounted for by causes which were pointed out by the Judges in their report.[1] They stated that the boiler only did half its duty—an affirmation which is precisely confirmed by the tabulated calculation.

TABLE 11.—PORTABLE-ENGINE BOILERS. RELATIONS of COAL and WATER.

Calculations of evaporative performance for surface-ratio 50.

No. of Boiler.	Grate-area as reduced for Trial.	Surface-ratios.	Coal per square foot of Grate per hour.		Water per square foot of Grate per hour for Surface-ratio, 50.		
			Actual.	Reduced in the ratio of the squares of the surface-ratios for ratio 50.	Reduced in the same ratio as for the Coal.	Calculated from column 5 by formula (25).	Difference by formula.
	Sq. feet.	Ratio.	lbs.	lbs.	lbs.	lbs.	Per cent.
12	2·00	102·0	31·10	7·473	69·28	84·27	+ 21·6
1	3·00	94·5	15·70	4·395	44·96	57·80	+ 28 5
8	2·37	89·0	20·40	5·73	60·11	69·28	+ 15·2
2	3·20	69·0	12·80	6·721	79·51	77·80	− 2·1
,,	,,	,,	12·50	6·564	77·52	76·45	− 1·4
10	3·50	54·0	20·70	17·75	176·20	172·60	− 2·0
6	3·20	50·0	9·53	9·53	103·80	102·00	− 1·7
4	3·75	45·0	10·32	12·72	140·10	129·40	− 7·6
7	4·70	34·0	13·00	28·11	262·30	261·70	− 0·2
3	5·10	33·0	14·80	33·97	155·90	312·10	+100·0
11	5·00	26·0	13·60	50·30	451·10	452·60	+ 0·3

[1] "The engine was indifferently managed." . . . . "It would appear that the boiler did about one-half, or rather less than one-half, its duty in making steam." —Report of the Judges, p. 17.

Looking to the evaporating capabilities of the portable-engine boilers in their ordinary condition, with unrestricted grates, it may be useful to show at what rates they are capable of evaporating water from and at 212°, in the ratio of 10 lbs. of water per lb. of coal consumed. For the calculation of these rates, the formula (9), p. 248, may be employed. It is

$$c = \frac{ar^2}{E - B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

The value of E is 10; of B is 8·6; and of a is ·008; and, by substitution, $c = \frac{\cdot 008r^2}{10 - 8\cdot 6}$; or

$$c = \frac{\cdot 008r^2}{1\cdot 4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

By this formula, the value of c, the quantity of coal consumed per square foot of grate per hour, is found, when the surface-ratio, r, is given for each boiler. Thence, multiplying by the grate-area, is found the total quantity of coal per hour; and 10 times the coal is the quantity of water. In this way the following table, No. 12, is calculated, in which the boilers are placed in the order of their normal surface-ratios. It is seen that No. 2 boiler is capable of evaporating at the given rate of efficiency, 8·15, say 8, cubic feet of water per hour. This is just 1 cubic foot per nominal HP., all the boilers having been designated of 8 HP. No. 11 boiler would only evaporate 3 cubic feet per hour, at the given rate of efficiency; whilst No. 1 is capable, by the calculation, of evaporating 16½ cubic feet per hour. It has already been seen that there is reason, in the design of its tube-surface, for doubting whether No. 1 is capable of so good a performance.

From the last line of the table, it may be assumed that the standard of average practice for portable-engine boilers of 8 nominal HP. is based on the following data, taken in round numbers:—

Nominal HP.	8 HP.
Area of fire-grate	5·5 square feet
Area of heating surface	220·0 „
Ratio of heating surface to grate-area, or surface-ratio	40 to 1.
Coal of good quality consumed per hour . .	50 lbs.
„ „ per HP. . .	6·25 „
„ „ per square foot of grate, say	9 „
Water evaporated, from and at 212° Fahr., per hour, at the rate of 10 lbs. per lb. of coal .	500 lbs. or 8 cubic feet
„ „ per HP. . . .	62·4 „ or 1 „
„ „ per square foot of grate, 91 lbs. say	90 „ or 1·45 „

TABLE 12.—PORTABLE-ENGINE BOILERS. CALCULATED EVAPORATIVE PERFORMANCE.

From and at 212° Fahr., at the rate of 10 lbs. of water per lb. of coal.

No. of Boiler.	Surface-ratio.	Grate-area.	Coal consumed per hour.		Total Water evaporated per hour.	
			Per square foot of Grate.	Total.		
	Ratio.	Sq. feet.	lbs.	lbs.	lbs.	Cubic feet.
1	64	4·40	23·40	102·96	1,029·6	16·50
10	54	3·50	16·66	58·31	583·1	9·34
6	50	3·20	14·30	45·76	457·6	7·33
4	45	3·75	11·57	43·24	432·4	6·93
2	41	5·30	9·60	50·88	508·8	8·15
12	37	5·50	7·82	43·01	430·1	6·89
9	35	4·30	7·00	30·10	301·0	4·82
7	34	4·70	6·60	31·02	310·2	4·97
3	33	5·10	6·22	31·72	317·2	5·08
5	31	6·13	5·50	33·71	337·1	5·40
8	29	7 20	4·23	30·45	304·5	4·88
11	26	5·00	3·86	19·30	193·0	3·09
Averages	40	4 84	9·14	44·24	442·4	7·09
To evaporate 8 cubic feet of water per hour.	40	5·46	9·14	49·92	499·2	8 0

GENERAL FORMULÆ FOR PRACTICAL USE.

In the French experiments with stationary boilers, the Lancashire and French boilers were, by the formulæ, p. 261, identical in performance; and the so-called "Fairbairn" boiler was within 3½ per cent. as effective as these. The three forms of boiler may therefore be accepted as equally efficient; and they may be classed with the Wigan boiler, as of equal efficiency, with coal of equal quality, and with equally good management.

The performance of the Howard boiler, as reported, is conformable to the formula for the Wigan boiler; and the Howard boiler is a type of the "sectional" kind of boilers.

The formula for the Wigan boiler is therefore applicable to all stationary boilers other than multitubular, with best coal and good management.

The performances of the Newcastle and Wigan marine boilers are nearly alike. Thus for a surface-ratio 30, the corresponding

quantities of water, w, for different rates of coal, c, per square foot of grate per hour, are as follows :—

Coal	$c =$	10,	20,	30,	40 lbs.
Newcastle boiler	$w =$	116·5,	213·6,	310·7,	407·8 „
Wigan boiler	$w =$	116·5,	224·0,	331·5,	439·0 „
Differences	$w =$	0·0,	10·4,	20·8,	31·2 „
Less than Wigan	$w =$	0·0,	4·6,	6·3,	7·1 per cent.

Halve the differences, and so take a mean of the formulæ; this will give a satisfactory general formula for marine boilers :—

$$\begin{array}{lll} \text{Newcastle} \quad . & w = & \cdot 02156r^2 + 9\cdot 71c \\ \text{Wigan} \quad . \quad . & w = & \cdot 01r^2 + 10\cdot 75c \\ \hline \text{Mean,} & w = & \cdot 016r^2 + 10\cdot 25c \quad . \quad . \quad . \quad (29) \end{array}$$

For coal-burning locomotive boilers, a mean of the two formulæ adduced, p. 263, which are nearly identical, will be a satisfactory formula :—

$$\begin{array}{lll} \text{S. E. Ry.} \quad . \quad . \quad . & w = & \cdot 009r^2 + 9\cdot 6c \\ \text{L. and S.W. Ry.} & w = & \cdot 009r^2 + 9\cdot 82c \\ \hline \text{Mean} & w = & \cdot 009r^2 + 9\cdot 7c \quad . \quad . \quad . \quad (30) \end{array}$$

The general formulæ which have been deduced are here collected together :—

Formulæ for the Relation of Coal and Water consumed in Steam Boilers, per square foot of Grate-area per hour; and the Ratio of the Heating Surface to the Area of the Fire-grate.

Stationary boilers .	$w = \cdot 0222r^2 + 9\cdot 56c$	. (31)
Marine boilers	$w = \cdot 016r^2 + 10\cdot 25c$	. (32)
Portable-engine boilers	$w = \cdot 008r^2 + 8\cdot 6c$	. (33)
Locomotive-boilers (coal-burning) .	$w = \cdot 009r^2 + 9\cdot 7c$	. (34)
Locomotive-boilers (coke-burning) .	$w = \cdot 0178r^2 + 7\cdot 94c$	. (35)

Limits to the Application of the Formulæ (31) to (35).

There are minimum rates of consumption of fuel below which these formulæ are not applicable. The limit varies for each kind of boiler, and it varies with the surface-ratio. It is imposed by the fact that the maximum evaporative power of fuel

is a fixed quantity, and is naturally at that point of the scale —say E in Fig. 2, p. 254—where the reduction of the rate of combustion for a given ratio procures the absorption into the boiler of the whole of the heat which is available for evaporation. In the combustion of good coal, the limit of evaporative efficiency may be measured by 12½ lbs. of water from and at 212° Fahr.; and in that of good coke, by 12 lbs. of water from and at 212° Fahr. The straight line E A, Fig. 2, represents the correct course of the diagram towards the zero point, indicating a proportion of $w = 12{\cdot}5c$, for coal; or $w = 12c$, for coke.

To ascertain the minimum rates of combustion of coal for stationary boilers, to which the formula (31) applies: the limit is reached when w becomes equal to $12{\cdot}5c$; or when $12c = {\cdot}0222r^2 + 9{\cdot}56c$, or ${\cdot}0222r^2 = (12 - 9{\cdot}56)\,c = 2{\cdot}94c$. By reduction, $c = \frac{{\cdot}0222}{2{\cdot}94}r^2 = {\cdot}00755r^2$. For a given surface-ratio, r, the limiting value of c is found by multiplying the square of the ratio by ${\cdot}00755$.

For the other kinds of boiler, the limiting values of c are found in the same way. They are here placed all together:—

Stationary boilers,	limiting value of c	=	${\cdot}00755r^2$
Marine ,,	,, ,,	=	${\cdot}007r^2$
Portable-engine boiler,	,, ,,	=	${\cdot}002r^2$
Locomotive-boilers (coal-burning)	,, ,,	=	$.00325r^2$
,, ,, (coke-burning)	,, ,,	=	${\cdot}0044r^2$

For lower values of c, or consumptions of fuel per square foot of grate per hour, the values of w, the corresponding quantities of water, are simply $12{\cdot}5c$ for coal, and $12c$ for coke.

The annexed table, No. 13, contains the limiting values of c for given surface-ratios, r.

The only limit to the application of the formulæ (31) to (35), to ascending values of c, or quantities of fuel per square foot per hour, is the limit of endurance of the fuel itself under the action of the draft—from 100 lbs. to 120 lbs. per square foot per hour, for ordinary hard coal or coke. Beyond this limit, the fuel is liable to be shaken and partly dispersed, unconsumed, by the force of the draft; although coke has been known to withstand the draft of a locomotive, when consumed at the rate of 130 lbs. per square foot per hour.

TABLE 13.—MINIMUM VALUES of c, or MINIMUM QUANTITIES of FUEL CONSUMED PER SQUARE FOOT of GRATE PER HOUR, for GIVEN SURFACE-RATIOS, to which the FORMULAS (31) to (35) ARE APPLICABLE.

—	Surface-ratios.						
	5	10	15	20	30	40	50
	Minimum Consumption of Fuel per square foot of Grate per hour.						
	lb.	lb.	lb.	lbs.	lbs.	lbs.	lbs.
Stationary	·2	·7	1·7	3·0	6·8	12·1	18·9
Marine	·17	·7	1·6	2·8	6·3	11·2	17·5
Portable	·05	·2	·4	·8	1·8	3·2	5·0
Locomotive (coal-burning).	·1	·3	·7	1·3	2·9	5·2	8·1
Locomotive (coke-burning)	·1	·4	1·0	1·8	4·0	7·0	11·0

	Surface-ratios—*continued.*					
	60	70	75	80	90	100
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Locomotive (coal-burning) .	11·7	15·9	18·3	20·8	26·3	32·5
Locomotive (coke-burning)	16·0	21·0	25·0	28·0	36·0	44·0

APPLICATIONS OF THE FORMULÆ FOR THE EVAPORATIVE PERFORMANCE OF STEAM BOILERS.

The Table No. 14 contains the relative quantities of fuel consumed and water evaporated, for surface-ratios, and rates of combustion per square foot of grate per hour, within the range of ordinary practice. It is seen that, with the surface-ratios 30 and 50, the boilers are, in the order of evaporative efficiency, as follows:—

Surface-ratio 30.	Surface-ratio 50.
Marine	Marine
Stationary	Stationary
Locomotive (coal-burning)	Locomotive (coal-burning)
Portable	,, (coke-burning)
Locomotive (coke-burning)	Portable.

Portable-engine boilers are clearly inferior in efficiency to coal-burning locomotive-boilers, and they may be constructed like these with sensible advantage.[1]

TABLE 14.—EVAPORATIVE PERFORMANCE of STEAM BOILERS for INCREASING RATES of COMBUSTION and DIFFERENT SURFACE-RATIOS.

For Best Coal and Best Coke, Surface-ratio 30.

Kind of Boiler and Fuel.	Water from and at 212° Fahr. per hour.	Fuel per square foot of Grate per hour in lbs.						
		5	10	15	20	30	40	50
		WATER.						
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Stationary. Coal. Formula (31)	Per square foot	62·5*	116	163	211	307	402	498
	Per lb. of coal	12·5	11·56	10·89	10·56	10·23	10·06	9·96
Marine. Coal. Formula (32)	Per square foot	62·5*	117	168	219	322	424	527
	Per lb. of coal	12·5	11·69	11·25	10·95	10·69	10·61	10·54
Portable. Coal. Formula (33)	Per square foot	50	93	136	179	265	351	437
	Per lb. of coal	10	9·3	9·01	8·95	8·83	8·77	8·74
Locomotive, Coal-burning. Formula (34)	Per square foot	57	105	154	202	299	396	493
	Per lb. of coal	11·4	10·5	10·26	10·10	9·97	9·90	9·86
Locomotive, Coke-burning. Formula (35)	Per square foot	56	95	135	175	254	334	413
	Per lb. of coke	11·14	9·54	9·02	8·75	8·47	8·35	8·03

* These quantities fall below the scope of the formulæ for the water, as explained in the text.

[1] The subject of this Paper is treated in the Author's work, "A Manual of Rules, Tables, and Data for Mechanical Engineers," 1876.

TABLE 14—*continued.*

Surface-ratio 50.

Kind of Boiler and Fuel.	Water from and at 212° Fahr. per hour.	Fuel per square foot of Grate per hour in lbs. 5	10	15	20	30	40	50
		WATER. lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Stationary. Coal. Formula (31)	Per square foot	62·5*	125*	187·5*	247	342	438	534
	Per lb. of coal	12·5	12·5	12·5	12·33	11·41	10·95	10·67
Marine. Coal. Formula (32)	Per square foot	62·5*	125*	187·5*	245	348	450	552
	Per lb. of coal	12·5	12·5	12·5	12·25	11·58	11·25	11·05
Portable. Coal. Formula (33)	Per square foot	62·5*	106	149	192	278	364	450
	Per lb. of coal	12·5	10·6	9·93	9·6	9·27	9·10	9·00
Locomotive, Coal-burning. Formula (34)	Per square foot	62·5*	120	168	217	314	411	508
	Per lb. of coal	12·5	11·95	11·20	10·85	10·45	10·26	10·15
Locomotive, Coke-burning. Formula (35)	Per square foot	60*	120*	164	203	283	362	442
	Per lb. of coke	12·0	12·0	10·91	10·16	9·42	9·05	8·83

Surface-ratio 75.

Kind of Boiler and Fuel.	Water from and at 212° Fahr. per hour.	Fuel per square foot of Grate per hour in lbs. 30	40	50	60	75	90	100
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Locomotive, Coal-burning. Formula (34)	Per square foot	342	439	536	633	778	927	1020
	Per lb. of coal	11·39	10·97	10·71	10·65	10·37	10·26	10·20
Locomotive, Coke-burning. Formula (35)	Per square foot	338	418	497	576	695	815	894
	Per lb. of coke	11·27	10·44	9·94	9·61	9·26	9·05	8·94

* These quantities fall below the scope of the formulæ for the water, as explained in the text.

EMPLOYMENT OF THE FORMULÆ (31) TO (35) FOR FUELS OF INFERIOR HEATING POWER.

1. To find the evaporative performance of a given quantity of inferior fuel per square foot of grate per hour: substitute for the given quantity the equivalent quantity of best coal, and find by the formula the water evaporated.

2. To find the quantity of an inferior fuel required for a given evaporative performance per square foot of grate per hour: find, by the formula in its inverted form, on the model of the equation (27), p. 266, the quantity of best coal required, and substitute for this amount the equivalent quantity of the inferior fuel.

NOTE.—In applying these rules, a heating power represented by an evaporation of 16 lbs. of water from and at 212° Fahr. may be taken as the standard for best coals, such as were employed in the trial of the Newcastle and the Wigan boilers.

TABLE 15.—HEATING POWERS OF FUELS.

No.	Fuel.			Heating Power of 1 lb. of Fuel.	
				Units of Heat.	Water evaporated per lb. of Fuel from and at 212° Fahr.
		Units.	lbs.	Units.	lbs.
1	Warlich's fuel			16,495	17·07
	Coal: Ebbw Vale, 1848	16,221	16·79		
	Powell's Duffryn, 1848	15,715	16·25		
	Llangennech, 1848–71	14,765	15·28		
2	Average (best Welsh)	15,567	16·11	15,567	16·11
3	Haswell Wallsend (Newcastle)			15,502	16·04
4	British Coals, Average			14,133	14·63
5	Coke			13,550	14·02
6	Lignite, perfect			11,678	12·10
7	Asphalt			16,655	17·24
8	Wood, perfectly dry			7,792	8·07
9	„ 25 per cent. moisture			5,565	5·80
10	Wood-charcoal, dry			12,696	13·13
11	Peat, perfectly dry			9,951	10·30
12	„ 25 per cent. moisture			7,156	7·41
13	Peat-charcoal, 85 per cent. carbon, dry			12,325	12·76
14	Tan, perfectly dry, 15 per cent. ash			6,100	6·31
15	„ 30 per cent. moisture			4,284	4·44
16	Straw, 14¼ per cent. moisture (probably)			7,600	7·87
17	Petroleum			20,240	20·33
18	Petroleum oils			27,531	28·50
19	Coal gas, mean of Ross and Harcourt			34,292	35·50

MEMOIRS OF DECEASED MEMBERS.

MR. JOSEPH PHILIP RONAYNE, M.P., son of Mr. Edmond Ronayne, the owner of large glass-works in Cork, was born in that city about the year 1820. His early education was pursued at the school of Messrs. Porter and Hamblin, many of whose scholars obtained distinguished honours at the Universities, and reached the highest positions in the Church, at the Bar, and in the medical profession. Subsequently he made himself thoroughly acquainted with fieldwork under Mr. O'Neill, a practical surveyor of the old school, and soon after entered the office of Sir John McNeil, M. Inst. C.E., who was then engaged in the design and construction of the main arterial lines of railway communication in Ireland. On these lines Mr. Ronayne was employed until under the late Mr. C. Nixon, M. Inst. C.E., he took charge, on behalf of the company, of the execution of the works on one-half of the Cork and Bandon railway. Although a short line, the works comprised a viaduct, a bridge, deep cuttings, and a tunnel upwards of a mile in length, all of which were successfully completed.

Up to 1853 the city of Cork was most inefficiently supplied with water. A small company furnished water to a few subscribers, but the Corporation bought up the company, and obtained an Act to levy rates, to procure a more abundant supply. In 1854 Mr. Ronayne published a pamphlet, in which he recommended a gravitation scheme. He proposed to form, near Blarney, at a distance of 4 miles from the city, a reservoir, 350 acres in area, and 80 feet deep. The nature of the ground was such that only a short embankment was required to impound the waters of this inland lake, of which the lowest point was 100 feet above the level of the city. A short cutting through a side valley would have opened an outlet for the waters. The reservoir would have contained sufficient for four months' consumption in the driest weather, and was to be fed, successively or simultaneously, by canals from the Blarney and Shournagh rivers, as well as by another important stream. The quantity of water to be delivered by this scheme was 50 million cubic feet per diem; which in addition to supplying the city with a sufficient quantity for domestic and ordinary manufacturing purposes, would yield from 3,000 HP. to 6,000 HP. available all the year round. Unfortu-

nately, other counsels prevailed; the gravitation system was rejected, and, instead of the natural head being utilised, the water is allowed to fall to the lowest possible level, whence it is pumped up by the expenditure of imported fuel, thus being a wasteful consumer, instead of being a source, of mechanical power.

About this time Mr. Ronayne was invited to proceed to California, to superintend some large hydraulic works to bring down the waters of the Sierra Nevada to the gold fields. He remained in that country from 1854 to 1859, where reservoirs and several miles of canals and aqueducts were executed from his designs and under his superintendence.

Soon after returning to Ireland, Mr. Ronayne became a contractor, and executed the Queenstown branch of the Cork and Youghal railway. On the completion of that work he laid out the Cork and Macroom railway, the Act for which was obtained in 1861, after a contest with a competing scheme which lasted eleven days in the House of Commons, and was fought again in the House of Lords. Subsequently he entered into a contract for the execution of this line, for which he took payment to a large amount in shares, all of which he retained. Thus he occupied the unusual position of being engineer, contractor, and the largest proprietor in the undertaking, a combination which led to the line being designed with economy, well executed and carefully managed, so that at present it probably earns a larger percentage than any other Irish line with a single exception. Later Mr. Ronayne took a contract for the Irish Southern line, joining Clonmel and Thurles, which is at present in course of execution.

Some years since, when the Government proposed to construct a dock for vessels of the Royal Navy near Haulbowline Island in Cork Harbour, Mr. Ronayne called attention to the great expense of constructing a dock in such a position, surrounded by water and much exposed to the weather, and pointed out that it was also within reach of the guns of an enemy's ships. He contended that, by an easily constructed embankment, a land-locked bay near Monkstown could be converted into a dock of immense area, with deep water up to its gates, in a position completely protected from the fire of an enemy, surrounded by extensive quarries of limestone and sandstone, supplied at one end by a stream of pure fresh water, and within a mile of existing railway communication. He suggested that the railway should be continued to the dock, and beyond it to Haulbowline, Spike Island, and Camden Fort, so that all the forts and stores of the harbour (except one) might be

brought into connection with the barracks at Cork and Ballincollig, and with the general railway system of Ireland. Although looked upon with favour by some Engineer officers, this plan was not destined to be carried out, and the Haulbowline site was finally adopted.

In 1872, a vacancy having occurred in the representation of Cork, by the death of Mr. J. F. Maguire, Mr. Ronayne was returned to Parliament for his native city; and again at the last general election he was placed at the head of the poll by a large majority. He was a leading member of the Home Rule party, and was looked up to by his colleagues for rare sagacity and unflinching honour. Clear-sighted, and of the strictest integrity, he was as much respected by his political adversaries as by his supporters. In private life he was endeared to all who had the privilege of his acquaintance by a noble generosity, a genuine spirit of self-abnegation, a modesty which could conceal neither his remarkable powers nor the brilliancy of his wit, a gracious manner, open-handed charity, and a kindly heart.

Mr. Ronayne was elected a Member on the 4th of March, 1856, but his pursuits, and distant residence, prevented him from taking any part in the proceedings of the Institution. He died on the 5th of May, 1876.

MR. EDWARD BALIOL SCOTT, son of Captain W. H. Scott, R.N., a lineal descendant of Baliol, King of Scotland, was born at St. Johns, New Brunswick, and was educated at Cullompton, Devonshire. His engineering career was commenced as a pupil of Mr. G. W. Hemans, M. Inst. C.E., with whom he remained three years, and by whom he was afterwards employed on the Midland Great Western railway of Ireland. In 1851 he went to Ceylon, where he held an appointment in the Public Works Department for five years, as Assistant Commissioner of Roads and Civil Engineer; this position he resigned, in the belief that there would be a larger field for promotion in India. Sir George Anderson, the then Governor of Ceylon, expressed his regret at parting with so good a public servant. Mr. Scott was next appointed by Mr. W. P. Andrew, Chairman of the Scinde Railway Company, as a District Engineer on that line, and remained in that capacity for five years, until the works of which he had charge were completed.

In 1862 he was employed by the Government of Bombay to

design and carry out a breakwater and harbour at Mandavie in Cutch, the native ruler of that province having applied to the Bombay Government for an engineer for the purpose. The plans for the breakwater were, when finished, submitted to the Government and highly approved, but owing to the opposition of the Hindoo population the native prince was compelled to abandon the project. Mr. Scott was afterwards employed by Sir Robert Wallace, then Resident of Baroda, in engineering works for the Guicowar. In 1864 he accepted an appointment under the Political Agent, as Consulting Engineer to the Nawab of Joonaghur in the Province of Kattyawar, to design and construct a breakwater and harbour at Verawul, and the new Bunder, &c., at Nowanuggur. He reclaimed a great portion of the foreshore, and, besides being occupied in carrying out the breakwater, designed and superintended other harbour and railway works belonging to the Nawab.

Mr. Scott was elected a Member on the 2nd of March, 1869, while in India, where he resided for eighteen years, without once coming home. He died on the 27th of April, 1875.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Application of the Theory of Continuous Girders to Economy in Bridge-building. By CHARLES BENDER.

(Transactions of the American Society of Civil Engineers, vol. v., p. 147.)

Consider a number of separate spans of length l_1, l_2, l_3 . . . in contact over the piers B, C, D, but not united continuously, subjected to given loads. Each separate span will be deflected according to its load, and the end posts of the girders before in contact will now be inclined at various angles to each other and to the vertical. Let γ_1, δ_1, γ_2, δ_2 . . be the angles which the end posts of each separate span make with the vertical. Suppose, now, that tensile forces are applied between the extremities of the top booms of two adjacent girders, and compressive forces between those of the bottom booms, of sufficient intensity to bring the end posts into their original positions. It is evident that under the action of these forces, if the loads on the separate spans were removed, the girders would be bent upwards in a manner similar to that in which they were previously deflected. Let α_1 β_1, α_2 β_2 . . . be the angles between the ends, posts, and the vertical under these conditions, and let M_1, M_2, M_3 . . . be the moments of couples formed by the tensile and compressive forces applied over the piers. Then the sum of the angles of downward deflection, at any central pier caused by the dead and live loads on the two adjacent spans, must be equal to the sum of the angles of upward deflection caused by the unknown moments applied, on the previous supposition, over the three piers of the two spans under consideration. Thus

$$\left.\begin{array}{l} \delta_1 + \gamma_2 = \alpha_2 + \beta_1 \,;\; \delta_2 + \gamma_3 = \alpha_3 + \beta_2 \\ \delta_3 + \gamma_4 = \alpha_4 + \beta_3, \text{ \&c. } \quad . \quad . \quad . \quad . \end{array}\right\} \quad . \quad . \quad . \quad . \quad (I)$$

the left-hand members of the equations being functions of the given loads, and the right-hand of the unknown moments M_1, M_2, M_3, &c.

For each intermediate pier there is one equation and one unknown moment. Then from the theorem of parallel forces, the angles of deflection of the single spans δ, γ, α, β, can be calculated and the values of the unknown moments found from them.

Let A B be a single-span girder of depth h, supposed to be without weight, resting on the supports A and B, and let a couple consisting of the two forces f and f be applied to the end of the beam over the support B, while the end A is retained on the point of support B by a downward force p, thus causing the beam to assume a form convex on the upper side. Let M be the moment of the couple acting over B; l the span A B.

Then the couple $hf = \mathrm{M}$ is in equilibrium with the couple $p\,l$; and the force p being supposed only sufficient to keep the end A in contact with the support, the reaction of the support B is equal to p.

Thus $$\mathrm{M} = h f = p\,l.$$

From this it is seen that in a loaded span the action of the couple f, f over B is to reduce the pressure on the support A, and by the same amount to increase that on B.

The same is true if at the other end of the span a couple of moment M_1 act; all that has to be done is to add together the effects due to each moment separately. In a beam of several spans if l_1, l_2, l_3 be the spans, $\mathrm{M}_1, \mathrm{M}_2, \mathrm{M}_3$ the moments over the piers, that over the abutment being equal to zero, p_1, p_2, p_3 the reactions at the piers, then

$$\left.\begin{array}{ll}\mathrm{M}_1 = p_1 l_1\,. & \mathrm{M}_2 = \mathrm{M}_1 - p_2 l_2 = p_1 l_1 - p_2 l_2 \\ \mathrm{M}_3 = \mathrm{M}_2 + p_3 l_3 = p_1 l_1 - p_2 l_2 + p_3 l_3 \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . & \\ \mathrm{M}_{n-1} = \mathrm{M}_{n-2} + p_{n-1} l_{n-1} = p_1 l_1 - p_2 l_2 + p_3 l_3 + \ldots \pm p_{n-1} l_{n-1} & \end{array}\right\} \text{(II)}$$

also $\mathrm{M}_{n-1} = p_n l_n$ if n be the number of spans.

There are thus n equations from which to find the n unknowns p_1, p_2, p_n in terms of the moments $\mathrm{M}_1, \mathrm{M}_2, \mathrm{M}_3$, &c.

To find the angles of slope α, β, γ, &c. :—

Let the modulus of elasticity of the iron of the girder be assumed constant throughout the structure = E. Let the beam have the same cross section throughout, moment of inertia = I. Let the diagonal bracing be so arranged that there is no doubt about the duty performed on each piece—this necessitates there being but a single system of struts and ties; and let the temperature be considered uniform throughout. Let $p_1, p_2, p_3 \ldots$ denote the reactions of the supports under the moments $\mathrm{M}_1, \mathrm{M}_2, \mathrm{M}_3 \ldots$, and $l_1, l_2, l_3 \ldots$ the lengths of the spans.

Then if α and β are the angles of slope at the free extremity of an end span, and the first pier over which the moment M acts, respectively,

$$\left.\begin{array}{l}\alpha = \dfrac{1}{6}\dfrac{\mathrm{M}\,l}{\mathrm{E\,I}} = \dfrac{p\,l^2}{6\,\mathrm{E.I}} \\ \beta = \dfrac{1}{3}\dfrac{\mathrm{M}\,l}{\mathrm{E\,I}} = \dfrac{p\,l^2}{3\,\mathrm{E.I}}\end{array}\right\} \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . \;\; . \;\; \text{(III)}$$

thus $\beta = 2\,\alpha$.

In the case of an intermediate span acted on at its two extremities by moments M_1, M_2, the angles of slope become

$$\alpha = \frac{M_1 l}{3 E.I} + \frac{M_2 l}{6 E I}$$

$$\beta = \frac{M_1 l}{6 E.I} + \frac{M_2 l}{3 E.I}$$

Finally to determine the angles of slope γ, δ, of a single span due to a load P on the span at distances a, b, from the extremities. These are shown to be

$$\left.\begin{aligned} \gamma &= \frac{P.a\,b}{6\,l.E.I}(a + 2\,b) \\ \delta &= \frac{P\,a\,b}{6\,l\,E\,I}(2\,a + b) \end{aligned}\right\} \quad \dots\dots\dots\dots \quad (IV)$$

When the single span A B carries a number of loads P_1, P_2, &c.

$$\gamma = \frac{\Sigma.P\,ab\,(a + 2\,b)}{6\,l\,E\,I}$$

$$\delta = \frac{\Sigma\,P\,ab\,(2\,a + b)}{6\,l\,E\,I}$$

From (I) $\delta_2 + \gamma_3 = \alpha_3 + \beta_2$, where $\delta_2 + \gamma_3$ are the angles of deflection due to the loads P_1, P_2, Q_1, Q_2, &c., and $\beta_2 + \alpha_3$ are the angles of elevation due to M_1, M_2 and M_3 of the spans considered as single. Whence, substituting for δ_2, γ_3, α_3, β_2 their values as follows:

$$\delta_2 = \frac{1}{6\,l_2\,E\,I}\,\Sigma\cdot P\,ab\,(2\,a + b) \text{ for span } l_2$$

$$\gamma_3 = \frac{1}{6\,l_3\,E\,I}\,\Sigma\,Q\,ab\,(2\,b + a) \quad \text{,,} \quad \text{,,} \quad l_3$$

$$\beta_2 = \frac{M_1\,l_2}{6\,E\,I} + \frac{M_2\,l_2}{3\,E\,I}$$

$$\alpha_3 = \frac{M_3\,l_3}{6\,E\,I} + \frac{M_2\,l_3}{3\,E\,I}$$

then the equation

$$\frac{1}{l_2}\,\Sigma\,P\,ab\,(a + 2\,b) + \frac{1}{l_3}\,\Sigma\,Q\,ab\,(2\,a + b)$$
$$= M_1\,l_2 + 2\,M_2\,(l_2 + l_3) + M_3\,l_3.$$

In the practical application of continuous girders the Author shows that the assumption of a uniform modulus of elasticity of the material is untenable. From his own experiments on eye-bars up to 40 feet in length he has found that the modulus of elasticity

varies from 18 millions to 40 millions of pounds. The results of different observers may be tabulated as follows:—

Experimenters.	Material.	Stress per square inch.	Modulus of Elasticity.
Bornet	Bars of chain iron.	..	35,500,000
"	"	20,000	28,500,000
Ardant	Soft annealed wire.	35,000	24,000,000
"	Hand-drawn wire.	42,000	27,300,000
Malberg	Best German stock bars.	..	20,000,000 to 27,000,000
Bender	Eye-bars, 1 to 14·25, sq. inches in section.	..	18,000,000 to 40,000,000

To form an estimate of the relative economy of separate and continuous span bridges the Author gives calculations of the stresses, sectional areas, and weights of two 200-feet railway spans on the two systems. Width between the trusses 14 feet, cross girders 8 feet apart, live load 1 ton per lineal foot with a maximum load from the locomotive of $1\frac{3}{4}$ ton per lineal foot on one panel at a time, of 16 feet length, the maximum stress 10,000 lbs. per square inch, shearing stress 8,000 lbs., the sections of struts with flat ends to be multiplied by the factor $\left(1+\frac{n^2}{5,000}\right)$, where n represents the length of a member divided by the least diameter of gyration of a well-built strut. The depth of girders to be designed so as to be the most economical.

The weight for the continuous spans is found to be 1,166 lbs. per lineal foot. Compared with this, taking a single span of 200 feet in length, 27 feet in depth, with the same live load as in the preceding case, the weights per lineal foot are found to be 1,063 or 1,017 lbs. according as the struts consist of lattice posts or hollow columns. The following table shows the relative economy of the systems in the struts, ties and booms:—

——	Continuous Girder.	Single span. With latticed members.	Single span. With hollow columns.
	lbs.	lbs.	lbs.
Struts	35,560	34,000	27,300
Diagonals	43,292	37,000	37,000
	78,852	71,000	64,300
Ratio	1·23	1·11	1·00
	lbs.	lbs.	lbs.
Booms	86,000	78,000	74,000
Ratio	1·16	1·05	1·00

The conclusions arrived at by the Author are that the assumption of a uniform modulus of elasticity is not borne out by experiment and cannot be maintained.

That even if it were the case, a correct theory would require one system of diagonals only to be used in a continuous girder. The theory does not take into account the influence on the bending moments and shearing stresses of the deflections, due to the extension of ties and the compression of struts.

That in the determination of the sectional areas, if a piece is exposed to tension as well as compression, it must be proportioned to resist the maximum tension plus the maximum compression.

Continuous girders badly built or erected may be subjected to much greater stresses than contemplated; in the case of a continuous beam of 200 feet span, 1 inch difference in the level of the bed-plate of a pier increasing the stress 16 per cent.

If the booms of a continuous girder are protected from the direct heat of the sun the stresses are much altered, and may be increased 30 per cent. by a variation of temperature of 30°, and at the points of contrary flexure more than 50 per cent.

A. T. A.

Construction and Cost of Light Branch Railways in Hungary.

By M. Fournier, Inspector-General of the k. k. privil. österr. Staatseisenbahn.

(Annales des Ponts et Chaussées, vol. xii., p. 603, 1 pl.)

The main South-Eastern railway from Vienna to Bazias passes, between Pesth and Temesvar, through extensive and fertile plains where the roads are very bad in consequence of the cost of proper material for repairing them. The large traffic in corn is consequently confined to the short period between the end of the harvest and the setting in of wet weather; and the railway accommodation and rolling stock, though more than enough during the rest of the year, are insufficient for the large amount of goods brought to the railway during this short period. Light branch lines, which would render the traffic more regular, and develop it, appear the proper remedy for the present defective means of communication. In consequence of the cost of ordinary road carriage, being on the average from 8*d.* to 9½*d.* per ton per mile, the three classes of rates allowed for light branch lines of 2·35*d.*, 3·3*d.*, and 4·7*d.* per ton per mile would insure the traffic being brought to them, would cause a great saving in the cost of carriage to the inhabitants of the district, and where the works are light would pay a good interest on the capital expended. In the case of more expensive cross lines, deemed necessary for the proper development of the resources of the country, higher rates might be charged to secure a fair interest on capital, as high rates for short distances do not materially affect the total cost of conveyance. The Austrian Railway Company, which works the State railways, has constructed, at the request of the inhabitants, the first two light

branch single lines from Valkany to Perjamos, and from Vojtek to Bogsan, with the standard gauge, so that the ordinary rolling stock can be used, but with rails weighing 51 lbs. per lineal yard instead of 74⅔ lbs., and a formation width of 13 feet. To encourage the construction of branch lines the State has remitted the duty and taxes on them for thirty years, and besides a reduction in the weight of rails and the formation width, has allowed a diminution in the size of the sleepers and the amount of ballast, the construction of bridges and other structures with wood, the simplification of the station arrangements and buildings, and a great reduction in the number of watchmen's cottages, on the condition that the speed is limited to 11⅔ miles an hour.

The Valkany and Perjamos railway joins the main line at Valkany, and is 29 miles long. The country through which it passes is slightly undulating, the earthwork is light, and the line has been laid out to afford the best accommodation for the district, and to avoid unnecessary works. The land required for the railway, amounting to 283⅔ acres, was given to the company, with the exception of 4 acres costing £123. The steepest gradient is 1 in 400, and the radius of the sharpest curve is 20 chains: the line is straight for nine-tenths of its length. The line was formed on an embankment throughout, taken from side cutting, as the additional land needed involved no expense, and the ground was sufficiently level, so that the earthwork was done cheaply and expeditiously. The total amount of earthwork was 257,680 cubic yards, or about 9,600 cubic yards per mile, and it cost 7·3*d.* per cubic yard. The ballast was laid 9 feet 2 inches wide at the top, and 10 inches deep, which gives 0·91 cubic yard per yard forward: the sleepers are 7 feet 8 inches long, 5 inches thick, and from 8¾ to 9½ inches wide. Special locomotives had to be constructed so that the weight on each pair of wheels should not exceed the weight on a pair of wheels of a loaded truck: they have three pairs of wheels coupled, and can draw a gross weight of 400 tons at the ordinary rate of speed of 9⅓ miles an hour on these light lines. The following table gives the details of cost:—

	£.	*s.*	*d.*
Surveys and superintendence	2,340	0	8
Transfer of land and fees	736	18	6
Earthwork for railway and stations	7,655	19	6
Stream bridges and culverts	1,758	19	0
Permanent way, including ballast	71,915	16	11
Station buildings (five)	7,242	19	11
Cranes, cisterns, pumps, fittings and pipes for water supply	3,585	7	2
Watchmen's cottages and level crossings	2,291	19	3
Station fittings	436	3	6
Telegraph with one wire	840	5	8
Preparations for working	43	19	5
Locomotives (three)	5,100	0	0
Share of expenses of junction	3,650	0	0
Interest on capital during construction	2,144	4	2
Total expenditure	109,742	13	8

The details of 1 mile of permanent way are as follows, the rails being 22 feet 11½ inches long:—

			£.	s.	d.	£.	s.	d.
Rails (51 lbs. per lineal yard)	80¼ tons	at	17	0	8·3	1,364	4	0
Fish-plates (7·716 lbs. each)	63·38 cwt.	„	0	17	0·4	53	19	7
Bolts (0·904 lb. each)	14·84 „	„	1	14	7·74	25	14	2
Spikes (0·683 lb. each)	44·92 „	„	1	2	4·2	50	4	0
Sleepers, 1,840 No.		„	0	2	4·8	220	16	0
Laying, carriage and sundries						523	6	11
Ballast						194	8	1
Switches, crossings, turntables and sundries						81	15	1
						£2,514	7	10

The works were commenced in March 1870, and the line was opened for traffic in October the same year.

The Vojtek and Bogsan light railway, joining the main line at Vojtek and the mineral line from Reschitza to Eisenstein at Bogsan, is 29 miles 3½ furlongs in length: it was authorized early in 1873, and was opened in September 1874. The earthwork was heavier, and the works more numerous and larger than on the Valkany and Perjamos railway, and a smaller portion of the land (about eleven-twentieths) was given to the company. The Bersava is crossed by a wooden bridge 157 feet long; the steepest gradient on the line is 1 in 125, and the radius of the sharpest curve is 20 chains. The amount of earthwork was 490,000 cubic yards, or about 16,600 cubic yards per mile, and it cost 9·68*d*. per cubic yard. The details of expenditure are as follows:—

	£.	s.	d.
Surveys and superintendence	6,522	0	5
Transfer of land and fees	3,035	13	8
Earthwork for railway and stations	19,544	13	1
Bridges and culverts	9,764	5	5
Permanent way, including ballast	57,926	11	1
Station buildings (six)	9,002	19	2
Cranes, cisterns, pumps, fittings and pumps for water supply	2,520	5	5
Watchmen's cottages and level crossings	2,865	11	5
Station fittings	883	2	9
Telegraph with one wire	911	7	0
Preparations for working	666	8	2
Locomotives (two)	4,230	15	2
Share of expenses of junction	3,767	0	0
Interest on capital during construction	4,771	9	6
Total expenditure	126,412	2	3

ONE MILE OF PERMANENT WAY.

			£.	s.	d.	£.	s.	d.
Rails, 80¼ tons		at	12	16	0·53	1,026	0	0
Fish-plates, 63·38 cwt.		„	0	12	9·6	40	11	0
Bolts,	14·84 „	„	1	4	4·62	18	2	6
Spikes,	44·92 „	„	1	0	3·85	45	12	10
Sleepers, 1,840 No.		„	0	2	5·47	225	18	9
Laying, carriage and sundries						251	1	0
Ballast						119	1	9
Switches, crossings, turntables and sundries						112	13	0
						£1,839	0	10

The Valkany and Perjamos railway cost £4,073 per mile, and the Vojtek and Bogsan railway £4,295 per mile: the difference is due to the heavier works and greater charge for land on the latter line, but this excess has been considerably reduced by the diminished cost of the permanent way.

L. V. H.

Railway Resistance. By P. H. Dudley and W. P. Shiner.

(The Engineering and Mining Journal [New York], vol. xxii., p. 36.)

The Authors give a description of some experiments in progress on the Lake Shore and Michigan Southern railway, and of the recording dynamometer or dynagraph with which the experiments were made. This instrument, attached to a car next the locomotive, consists of a steel cylinder filled with oil, fitted with two pistons, respectively 4 inches and 1·25 inch in diameter, and so arranged that either can be used. The drawbar of the car is attached directly to the piston which forces the oil through a pipe to a small cylinder, in which is fitted a piston acting against springs of known resistance. This small piston actuates a pencil which records upon moving paper the amount of force exerted. The paper is in lengths of from 150 to 400 feet and 10·75 inches in width, and is moved by direct motion from the car axle. Usually 0·25 inch represents 100 feet of the track passed over, an electrical chronograph records every 7·5 seconds, so that the speed for any given yard can be calculated. The dynagraph curve or line indicates, by its height above a datum, the force required at any instant to draw the load, while its irregularities indicate the variation in that force due to inequalities and other defects of the road, the exact position of the inequalities being also recorded. Every movement of the throttle valve or reversing lever can be detected on the dynagraph line: indeed this line exhibits the effects due to the performance of different engines and of different drivers, and thus by passing over a track its condition as well as that of the engine is recorded.

Diagrams were taken from Cleveland to Chicago and back, and from Buffalo to Chicago and back, part of the line being in good condition with steel rails and part with iron rails. With a stock train of 709 tons (of 2,000 lbs.), at a speed of 16 to 18 miles per hour, the resistance upon a straight line was from 6·5 lbs. to 7·1 lbs. per ton. A train of equal weight, but made up with box cars, did not differ materially as to resistance.

The cars were fitted with chilled wheels, 33 inches in diameter, with broad tread covering about 1·125 inch in 4 inches, and weighing 550 lbs.; the journals range from 2·875 to 3·25 inches in diameter, and 5·5 inches to 8 inches in length, the lubricant being petroleum in a nearly crude state. In all the experiments with single cars it was found that those fitted with 6-inch brasses ran easier than those with shorter journals, and were not so liable

to heating, the latter taking place more particularly with brasses not sufficiently stiff to prevent springing off from the journal at their ends. With reference to the system of lubrication, it is noticed that the waste oil catches the brass ground off the bearings, and in being constantly re-used keeps the journal only in an unctuous, and not in a well-lubricated state. In some cases, where the oil and brass-dust were found mixed into a thin paste, fresh oil reduced the frictional resistance by from 10 to 20 per cent. One object in the construction of the dynagraph has been to ascertain the friction of various kinds of equipment in use in the eastern and western coal districts. In the former the cars weigh from 50 to 55 per cent. of the load, and in the latter, with 28 feet length over all, the weight is from 80 to 95 per cent. of the load carried. All the experiments suggest the conclusion that the long heavy trains of from 700 to 750 tons could be run with less fuel at the rate of 18 to 20 miles per hour than at 12 miles, their regular time-table rate.

In these experiments it has not been found that the power required to move a train increases as the square of the velocity; on some simple cars it only increased as the square of the velocity of the wind acting on the frontage, the friction remaining an almost constant quantity, though it is not thought that this will hold good for all kinds of cars. Reference is made to the cost of stopping and starting heavy trains. It was noticed, that with the train weighing 709 tons, it required a run of from 2 to 2·5 miles to get the train under motion, and that the consumption of coal in overcoming the inertia of the train was as much as would drive it 2 miles, the cost of such stoppings, including fuel, water, and watchmen at level-crossings, being from *22d.* to *25d.* (45 cents), without taking into consideration the extra wear of rolling stock, permanent way, and the loss of time and source of danger. The most notable increase of resistance of trains was found in passing over iron rails with joints, mostly opposite, from 0·5 to 1·250 inch lower than the centre of the rail, and on a good steel way the increase of resistance due to shocks varied from nothing to 4,000 lbs. Iron rails are found to possess insufficient elastic resistance, and to take a permanent set from the blow of every wheel that passes over them, the ordinary fish-plate joint being quite incapable of sustaining the ends of the rails, especially on shallow-ballasted tracks. The locomotives used in the experiments have been small, with boiler and tender rigidly attached; their running was attended with constant oscillation, which had some effect on the diagrams taken.

In all the experiments, when the weight of the cars was partially carried upon the ends of the truck frames, it was found that, after passing curves or switches, long distances were often run before the framing became re-straightened by eliminating the curvature impressed upon it while traversing the curve, when the tendency of the train to straighten was resisted by the flanges of the wheels.

At present no apparatus has given uniform results as to the

effect of the wind, though the most sensitive anemometers and vanes have been tried. It is considered that the diagrams taken in these experiments give information of great value for determining the relative economic efficiency of different engines for freight purposes; and in further experiments every detail of construction which can affect the resistance of cars will be considered for the purpose of arriving at what is best, and to initiate a system of uniform construction of cars intended for the same purpose, the expense of keeping in stock a large variety of wearing parts for cars of different construction involving a large tax upon transportation. No attempt has yet been made to formulate the experimental results, but a tabular statement is given of the values obtained in experiment, with single empty cars, with two empty cars, with three and four empty cars, and with one and two loaded cars; and the following exhibits some of the observed resistances on different fully-loaded trains:—

Where run.	Weight of Train.	Speed in miles per hour.	Loaded Cars.	Empty Cars.	Resistances in lbs. per ton.
	Tons.				
Toledo to Cleveland . .	590	20	29	2	1·45 (*sic in orig.*)
Cleveland to Erie . . .	709	20	37	..	6·85
Erie to Buffalo	512·4	..	25	2	7·94
Cleveland to Wellesville .	313	..	..	..	10·72

The rails from Wellesville to Cleveland are iron, much depressed at the joints, with many inclines of 1 in 132 and some sharp curves; while from Cleveland to Erie the rails are of steel in good condition, the line being almost straight, and the gradients not exceeding 1 in 310. These two examples show resistances varying as 100 to 157; but when the tonnage moved per mile per lb. of coal was compared, it was found to be nearly the same in the two cases, so that the work done on the iron road per lb. of coal was 50 per cent. greater than on the steel, showing that the effect obtained per lb. of coal on the latter road was much inferior to that on the former. These results are quoted to show the error of comparing the work performed upon one road with that of another by the tonnage moved in miles by 1 lb. of coal.

Five diagrams accompany these Papers as made by the dynagraph; they illustrate the differences of resistance on lines in good and bad repair, the diagram from one part of the steel line being almost uniform, while on the track out of repair, and on the iron rails, the dynagraph curve fluctuates through wide ranges. The diagrams also show the power expended in getting the train under motion, and by it the cost of stoppages.

W. W. B.

On the Durability of Impregnated Sleepers. By Leopold Huber.

(Wochenschrift des Oest. Ingenieur- und Architekten-Vereines, vol. i., p. 230.)

The Author gives the data read at the meeting of Engineers of the "Verein Deutscher Eisenbahnverwaltungen," in Constanz, by Herr Fünk, from observations made partly on the Cöln-Minden railway, and partly on the Hanoverian State railway; and supplements the report by a statement of his own experiences on the Kaiser Ferdinand Nordbahn in Austria.

Result on German Railways.

Material of Sleeper.	Matter with which impregnated.	No. of Years' Duration.	Percentage of Renewal. Per cent.
1. Pine	Chloride of zinc	21	31·0
2. Beech	Creosote	22	46·0
3. Oak	. . . .	17	49·0
4. "	Spirits of tar containing creosote	17	20·7

Result on Austrian Railway.

1. Pine	Chloride of zinc	7	4·46
2. Oak	. . . .	12	74·48
3. "	Chloride of zinc	7	3·29
4. "	Spirits of tar containing creosote	6	0·09

W. E. T.

The New Harbour Works at Trieste. By F. Bömches.

(Allgemeine Bauzeitung, vol. xli., pp. 24 and 58.)

The improvement of the harbour of Trieste was begun in 1650, and continued at intervals until 1857, when the railway was opened. At that period, however, it was found that the increase in the size of trading steamers, the communication with the railway and other means of transport, the large increase of traffic, and the want of shelter, rendered a thorough change necessary. The Austrian Government consequently appointed a commission of professional men to examine a project proposed by Talabot, which in 1867 served as the basis for a contract between the State and the "K. K. priv. Südbahn-Gesellschaft," the latter undertaking to carry out the works in twelve years for 13½ million florins.

The new harbour is formed by a quay, more than 1,300 yards long, on the north-east shore of the former roads, from which project four moles. The widest, nearest the sea, is from 320 to 390 feet broad and 720 feet long. The breadth of the second is 260 feet, its length 620 feet. The respective dimensions of the third

and fourth are, breadths 260 feet each, lengths 656 feet and 426 feet. A breakwater, 1,200 yards long and 45 feet wide, parallel to the wall of the shore, affords the necessary shelter. The wharfage area in the new harbour amounts to 72 acres. The quay and moles have an aggregate length of 4,300 yards, with a depth of water of 28 feet below mean low water. The three basins between the moles, respectively 920 feet, 950 feet, and 850 feet broad, have a depth varying from 28·8 feet to 43 feet.

Throughout the site of the new works the bottom consists of mud, extending to a considerable depth, and whilst black and fluid at the surface, becomes more consistent with increasing depth, till it gradually passes to a mixture of blue clay and sand. During the construction of Mole No. 1, the unstable nature of the foundation gave rise to serious displacements of the inclosing walls. They were formed of concrete blocks on a layer of coarse rubble thrown in on the natural bottom and finished above low-water line with ashlar and rubble masonry. Upon proceeding with the filling, the lateral displacement of the walls became so considerable, that it was found impossible to bring the mole back to the original dimensions. To avoid this in the construction of the other three moles the bottom was dredged to a depth of 39 feet, and a layer of coarse rubble, from 9 to 13 feet thick, was deposited as a foundation. It was made considerably wider, and the slopes, which had been 1 in 2, were altered to 1 in 4.

Within the line of the facing walls a prism of rubble was carried to 1 foot above low-water line, and the filling of the mole was completed before the construction of the walls was begun. In spite of these precautions there were slight settlements and lateral displacements, which, however, admitted of correction. In consequence of these settlements the mud in the basins, particularly near the walls, rose and had to be dredged with care, but not until some time after the completion of the moles, so as not to occasion new disturbance. The total filling, amounting to about 5,232,000 cubic yards, and consisting of $\frac{2}{5}$ of clay, earth, &c., and $\frac{3}{5}$ of rough sandstone blocks and rubble, was laid in horizontal and uniform layers, each of which was allowed to settle before the next was begun. The shore blocks in the rubble prisms varied greatly in size, some weighing as much as 78 cwt.; those weighing more were used in the pitching of the outer slopes of the breakwater.

Whilst constructing the facing walls of Mole No. 1, the foundations gave way to such an extent, that instead of four layers of concrete blocks, on an average eight were required. To prevent this serious waste of material in the other moles, it was decided to complete the filling before beginning the concrete wall.

The concrete blocks were prepared in a large open yard in the usual way, and were lowered into position from a barge by a steam crane carried by a pontoon. Previous to this, the rubble at the base had been properly levelled by divers, and covered with a layer of similar but smaller material, 1 foot thick, so as to form a

uniform bed. In setting the first course, divers ascertained the perfect bearing of the blocks; the other courses were placed by the crane only. As soon as two courses were in position the filling was thrown in between them. When the four courses were completed, three layers of blocks were temporarily placed on the top, and also others in front of counterforts to increase the stability of the wall against the internal pressure of the filling. These were not removed until after one year or two years, when the settling in the filling had completely ceased. Great care was taken to lay the blocks perfectly horizontal and to alternate the joints, which formed open fissures of from 3 to 3½ inches in width, an arrangement which was calculated to render the wall more apt to follow the undulation of the ground.

At Mole No. 1, where the facing walls were erected before the filling had been thrown in, almost the whole work had to be taken down and rebuilt. The reconstruction turned out to be troublesome and costly, entailing the removal of the loading, and the setting of the concrete blocks by steam crane and divers, the formation of a new level surface on the rubble bed, the re-erection of the concrete block wall, and the dredging away of the mud and rubble thrown up along the line of the quay-wall.

The longest and most difficult of these operations was the removal of the concrete blocks, which took four times as long as the setting. When completed the walls were carefully observed for one year, and, no settlement being apparent, the joints of the top row of blocks were filled in with cement mortar, the surface properly levelled, and the rubble masonry commenced.

In dredging the basins, precaution was taken to excavate the whole area first to a depth of 20 feet, then to 23 feet, and finally to 28 feet, to avoid subsequent movements in the foundations of the moles; but this proved of little avail. The dredgers used for excavating the basins raised the mud in the usual way by buckets supported by a ladder passing through a central well.

Numerous plates accompanying this Paper give full details of the sections of the moles and breakwater, of the machinery used in the manufacture of the concrete blocks, of the cranes, and of the dredgers.

A. O. B.

On the Currents in Navigable Rivers. By M. A. Rullier.

(Revue Maritime et Coloniale, vol. l., p. 447, 38 woodcuts.)

Rivers in their flow tend to wash the materials of their banks into the bed of the stream. When the current is gentle, the silt and clay in the banks are deposited in the centre, and the sandy portions at the sides; the bed of the river is gradually raised, and the width increased. When the current is rapid the banks are undermined, the lighter particles are carried away, and the heavier portions remain at the sides impeding the undermining action, and

the bed of the river is deepened: this action continues till the current slackens, when the banks again gradually resume their original slopes. The navigation of the straight reaches of a river presents no difficulty; the greatest depth is in general in the middle, and large vessels always follow the centre of the stream, but vessels of small draught when ascending the river hug one of the banks, as the force of the current is less at the sides than in the centre. When the river is shoal on one side the current is diverted towards the opposite bank, which assumes a perpendicular face, indicating thereby the existence of a shoal on the farther side. When banks are formed in a river whose course is straight, they usually are found in the centre, of an oval shape in plan, and triangular in longitudinal section; their presence, when below water, is manifested by the deviation of the current and by the ripples they give rise to, behind which the water is smooth. Occasionally the channels on either side of the bank are equally suitable for navigation, but more frequently one channel deepens at the expense of the other, and this is indicated by the steepness of the banks of the deeper channel. When the river takes a bend the direction of the current does not at once follow the altered line of the banks, but approaches the concave bank, and brings the greatest velocity and the greatest depth of the river near that bank. The concave bank is gradually encroached upon, and a deposit is formed near the opposite bank, and the river frequently increases in breadth at the bend. On account of the direction the current takes at a bend, vessels ascending the river hug the convex bank, and, when descending, keep near the concave bank. If the bend is very sharp, the stream is directed with considerable impetus against the concave bank, and, washing away the bank and scouring the bed, strikes across the river towards the opposite bank; silting takes place at the convex bank, which becomes pointed and has a gentle slope, whilst the concave bank is vertical. When the course of the stream is a curve of small radius, the river has generally a small breadth in proportion to the amount of its discharge; the strength of the current merely approaches the concave bank, and banks are rarely formed in the bed of the stream. When the river curves gently and runs through a loose soil it increases in breadth, diminishes in depth, and banks are frequently formed in the middle.

Through narrow passes the depth of a river is usually considerable, and its flow rapid; in these places vessels are always obliged to keep to the centre of the river so as to avoid the whirlpools and back currents caused by projections from the banks. A tributary flowing into a straight reach of a river leads to the formation of a bank, where the current of the tributary is checked by impinging upon the main stream, and, other conditions remaining the same, the size of the bank is proportional to the angle of inclination between the two streams. The best channel for vessels is generally on the side where the tributary flows in, except when the latter is very small. When the junction of the tributary

occurs at a bend in the river on the concave side, the bed is scoured on that side, and a deposit is formed at the point where the bank and the tributary unite; the convex bank is little affected by the confluence of the two streams. If the mouth of the tributary is on the convex side of a bend in the main river, the tributary, finding little resistance at its mouth, on account of the sluggishness of the river round the convex bank, continues its course for some distance across the main stream till it gradually merges into it, turning the direction of the current, when the tributary is strong, still more against the concave bank and increasing the encroachment on that side. When the main stream takes a sharp bend and the tributary flows in on the concave side, the result is very similar to the case just considered. A tributary flowing in where the river is curving gently, and above the part where banks tend to form, renders the navigation very complicated, as a bar is formed which sometimes extends so as to unite with the banks in the river. The navigable channel is almost always situated close to the mouth of the tributary, gradually tending towards the centre of the river. When the junction occurs where the river is obstructed by banks, the waters of the tributary assist in opening a passage through the banks and improving the navigable channel.

The Author explains at some length the proper measures to be adopted, in river navigation, in casting and weighing anchor, and the course that should be followed by a vessel going up or down a river in the various cases mentioned above.

L. V. H.

The Cavour Canal. By M. Oppermann.

(Nouvelles Annales de la Construction, 3rd series, vol. i., p. 94, 2 pl.)

In 1844 Rossi of Vercelli demonstrated from levellings that it was possible to irrigate the whole plain of Piedmont by the waters of the Po; and in 1853 M. Charles Noé was instructed by Count Cavour, on behalf of the Italian Government, to draw out a plan for carrying out this project, but its execution was delayed by the pressure of political affairs till 1862, when the scheme was taken up by an English company, which undertook to execute the work in accordance with M. Noé's plan, which was estimated as follows:—

	£.
Canal works	2,136,000
Purchase of the State canals in the district	812,000
Purchase of private rights, branch canal works and sundries	252,000
	3,200,000

The total cost of the works amounted eventually to £4,104,000, the increase being caused by additional works, of which the largest

was a canal for procuring water from the Dora-Baltea, and by the interest paid on capital during construction. In return for their expenditure the Company was granted a concession of the profits from the canal for fifty years, and a monopoly of the right of supplying water for irrigation within the limits of 984 feet from the main canal, 656 feet from the branch canals, and 328 feet from the conduits.

The Cavour Canal commences at the Po, ¼ mile from Chivasso, and not far from Turin, and terminates in a junction with the Tessin above Novara. Its length is 51 miles 172 yards, and its total fall 71·3 feet. The height of the side-banks above the bottom of the canal is 12 feet 6 inches for the first 38 miles 6 furlongs, 11 feet 6 inches for the next 7 miles 2 furlongs, and 10 feet 6 inches for the remainder. The bottom width of the canal is 131 feet for the first 5 furlongs, and then decreases gradually to 65½ feet at 5 miles 4¾ furlongs, and it continues at that width from that point to 38 miles 6 furlongs, where the canal feeds the Roggia-Busca. From 38 miles 6 furlongs to the Terdoppio at 46 miles, the bottom width of the canal is 41 feet, and 24 feet 7 inches for the remaining distance. The Company were authorized to draw 24,200 gallons per second from the Po; but when the river is at its lowest its discharge is only from 7,040 to 20,200 gallons per second, consequently it was found necessary to construct a canal to the Dora-Baltea for obtaining a supplementary supply. A bridge, with nine arches, of 52½ feet span, resting on piers 9½ feet wide at the springing, carries the canal over the Dora-Baltea; five oval siphon culverts, 7 feet 6½ inches high, and 14 feet 1 inch wide, carry the canal under the Sesia; and similar siphons convey it under the Elvo, the Agogna, and the Terdoppio. There is a dam with sluice-gates at the junction of the canal with the Po, for drawing the supply of water from the river, and also where the water is drawn from the Dora-Baltea. The weirs on the canal are in some instances made with an inclined fall over a masonry apron, the rush of water being checked by an apron inclined the opposite way, and a sill at the top; in other places, especially where the line of the canal is not straight, the water falls vertically over the weir upon a rubble mound at the bottom. The Lomellina, which is the largest of the branch canals, starts from the main canal near Novara; it is nearly 14 miles 5 furlongs in length, and serves to irrigate the country lying between the Agogna and the Tessin. It was made in 1871-2, at a cost of about £92,000. The average allowance of water for irrigating 1 acre is 320 gallons per hour, but varies according to the crop. The rate for supplying water directly from the Cavour Canal, or from a branch canal within 5 furlongs from it, is £136 a year for the supply of the standard quantity of 22 gallons of water per second; for distances between 5 furlongs and 3 miles 1 furlong the rate is £104, and along the old canals £68; and lower rates at greater distances.

L. V. H.

On the Effects of the Floods on the Danube Regulation Works near Vienna. By G. VON WEX, Chief Engineer of the Works.

(Zeitschrift des Oest. Ingenieur- und Architekten-Vereins, vol. xxviii., p. 77.)

The Author commences his Paper by a tabular statement, showing the highest floods which have taken place in the Danube since 1829; the water-levels on the Upper Danube; the corresponding levels near Vienna, and the causes and consequences of these floods, which he shows to have mostly arisen through the free passage of the ice having been blocked at some point in the circuitous and meandering course of the stream. Summer floods have almost invariably passed off without any disastrous effect; while, on the contrary, those caused in winter or early spring by a sudden thaw, created severe inundations of the lower portions of the city and suburbs in the years 1830, 1847, 1849, 1850, 1862, and 1871. The first of these was attended with great loss of life.

The new river works were carried on in the main stream, which describes a large curve on the north side of the city of Vienna, the latter occupying approximately the centre (or concave side) of the curve. A branch of the Danube (called the "Canal") formed a reverse curve and intersected the northern portion of the town. The main stream was very variable, shifting, shallow, and full of branches and backwaters. The two ends of the curve were therefore united by a main channel, forming a slightly curved chord of 7,260 yards long, 311 yards wide, and 12 feet below low-water mark. The main stream is thereby brought about 1½ mile nearer Vienna. At the same time the "Canal" itself was dredged to a uniform depth of 7 feet, its banks raised 20 feet above low-water mark, 82·9 yards apart, and a new mouth excavated in connection with the new main channel. Another reverse curve of the stream, somewhat lower down, is in course of similar regulation.

The amount of danger attending the winter floods depends on the severity of the winter, and on the strength and quantity of the ice which stops up the river. Floods have arisen without any great influx from the tributaries, simply because the river has been choked by huge débris and floating ice, which have gradually frozen into one compact mass. This latter phenomenon has taken place several times in the Danube canal, and has thereby raised the water-level in this branch from 3 to 10 feet above that in the main stream, with the most lamentable consequences for the city. A floating gate or caisson was therefore erected at the entrance of the canal, which it was hoped would keep a great deal of ice out, while allowing the water to pass under it. In the course of the severe winter of 1875–76, the Danube, from below Pesth to about 20 English miles above Vienna, a distance of 236 miles, was blocked with ice, and in some places frozen throughout. A sudden thaw occurred from the 16th to the 17th February, and the upper tributaries brought down masses of melted snow. The

ice above Vienna began to move on the 18th, and was, in the course of the next two days, driven with great violence against the frozen masses at Petronell and Haimburg (about 10 miles down stream), where, in fact, perfect mountains of ice were formed by the pressure; at the same time the water-level at Linz (125 miles up stream) was no less than 14 feet 3 inches above zero. The circumstances were therefore more unfavourable than they had been for forty-six years, since the upper floods were as high as they had ever been, while the river was completely frozen over for more than 100 miles of its lower course.

Serious inundations of the city were expected. They occurred at numerous towns above and below Vienna, and would no doubt have occurred in the capital, if the works had not been in a forward state. The ice, however, steadily continued to flow down the newly-dredged channel, and it was only in the second down-stream and unfinished chord or channel that a block took place on the 18th and 19th February, which raised the level of the water at the military baths from about 14 feet to 18 feet 7 inches above low-water mark, but only affected the Franz-Josef bridge (nearly due north of the town) to the extent of about 18 inches, and caused the eastern portions of the Prater and some outlying houses to be inundated.

Further, while in previous years the water-level at Nussdorf (at the up-stream commencement of the works) has reached 15 feet 10 inches, and even 18 feet, this year the facilities for the flow afforded by the new channel were such that the level never exceeded 14 feet, and only reached even this figure during a few hours.

The caisson at the entrance of the Danube canal kept the level of the water in the latter about 3 feet below that in the main stream; and although a great deal of ice dived under the caisson and floated down the canal, no block took place in it except at the uncompleted new mouth: this caused an inundation of a low-lying district (Erdberg), without any further serious results.

The above-mentioned block in the unfinished portion of the new channel caused a portion of the northern flood-bank to give way, and the water entered the old channel, but the damage was inconsiderable. The five great bridges, the quay walls (1,850 feet long), the many landing-steps, the new town baths, and the caisson itself, were unhurt, while the destruction of property was confined to a few mills and temporary buildings standing on the ground within the future flood-banks, and to some huts in the Erdberg district. The width of the channel fixed upon (311 yards, besides 518 yards more for the flood-waters), has proved amply sufficient to keep the level down to 12 feet 8 inches above low-water mark in any future floods; the quantity of water passing through having been calculated never to exceed 7,840 cubic yards per second.

The flood-banks are being restored, and the lower portion of the channel completed; while the works proposed on the Danube canal

will, it is believed, prevent any future block. It is intended to adopt some contrivance for preventing the ice from passing under the caisson; to dredge out the mouth of the canal, and further to raise and protect its banks.

E. D'A.

On the Means for Protecting the County of Torontál (Hungary) from the Inundations by the Rivers Theiss and Maros.

By B. Gonda.

(Journal of the Hungarian Society of Engineers and Architects, Buda-Pesth, vol. vi., p. 276.)

Although Hungary furnishes a considerable portion of the wheat produced in Europe, its culture is much impeded by the annual inundations to which large and fertile tracts have been for several hundred years exposed. The plains extending on both shores of the river Theiss, for instance, suffered so severely that the soil became almost worthless, and produced nothing but reeds. In 1822 the society formed for the protection of these plains accepted the plan of its engineer to embank 488,730 acres, which work was completed in 1844.

In 1855, an immense inundation having destroyed all these works, it was agreed that the proprietors of the grounds subjected to inundations should provide the works of protection, with the aid of the company. To fix the amount of contribution, an accurate survey was made, and each contribution determined by the position of the land as regards the rivers, and the length of time during which it was exposed to inundation.

The area of inundation was divided into three parts, and it was decided that the proprietors of the first strip, extending from Szegedin to Frányova, should pay annually 6 per cent. of their net income; those of the second part, viz., from the east of the county of Torontál to Vinczeér, $4\frac{1}{2}$ per cent.; and those of the third part, from the Vincze Bridge to the Bega Canal, from 2 per cent. to $4\frac{2}{3}$ per cent.

The company was thus enabled to continue its efforts, but in 1871 the heavy rainfall so increased the volume of the Theiss, and its tributaries the Maros and the Aranka, that the embankment burst at more than a hundred places. It was therefore resolved to strengthen all the banks, to enlarge the bed of the Aranka, and to construct several small sluices; also to widen the main sluice, and to connect the Theiss regulation with the adjacent Kovacsicza, Aranka, Kerektó, Böge, and Galaczka canal systems. The cost of this junction, which is in progress, was estimated at £171,500, the safe discharge of superfluous water, it is hoped, being thereby secured. The embankments already erected contain 1,700,342 cubic yards of earth, and £247,122 have been spent for new works and repairs.

L. E.

The Embanking of the Durance in the Department of Vaucluse.

By M. Hardy.

(Annales des Ponts et Chaussées, vol. xi., p. 518, 1 pl.)

The rich alluvial lands in the valley of the Durance have been constantly exposed to floods, in consequence of the great inclination of the bed of the river; and works for protecting portions of the lands from inundation have been executed from time to time. Till the year 1808 no arrangement for combined action of the landowners had been made; and embankments constructed on one side caused the river to encroach upon that opposite. In that year, however, Boards were appointed for conducting the work of embanking the river, at the expense of the proprietors of the adjacent lands, aided by a grant of one-third of the cost from the State; and a Commission, appointed in 1825, devised a comprehensive scheme, which was finally approved by the Government in 1845, and is still in course of execution. It was decided to confine the ordinary flow of the river within banks, below flood-level, formed of rubble stone, and to restrict the area of inundation by constructing T shaped walls behind them, raised above flood-level. The width between the former was fixed at 820 feet where the Durance enters the department of Vaucluse, increasing to 1,300 feet near its junction with the Rhone. The walls constructed to limit the area of flooding consist of four portions. (1) At the upper part a dam of earth and gravel is formed, either joining an embankment higher up, or a part of the valley above flood-level. (2) Lower down in the valley, where the stream in time of flood acquires sufficient force to wash away a mere earth formation, a dyke with a pitched slope on its exposed side is constructed, and carried down the valley as far as it can effectually resist the force of the current: the lower portion of this is always made at right angles to the river-bank, but its upper portion, and the earth dams above, may, according to circumstances, be either parallel, oblique, or at right angles to the low bank. (3) A mound of rubble stone is next formed, in continuation of the dyke with a pitched slope, but separated from it by a cross wall, 3 feet 3 inches thick, with counterforts in the middle, to provide against infiltration of water. (4) Lastly, a longitudinal dyke is formed, at the extremity of the mound of rubble stone, and at right angles to it, giving the embankment a T shape as it extends on each side of the point of junction, the upper arm being made from 200 to 260 feet long, and strongly constructed with rubble stone, as it is exposed to the whole force of the floods, and serves to protect the transverse bank from the rush of the current: the lower arm of the dyke prevents the current from running along the lower slope of the transverse bank, and gradually washing it away, and its length is from 80 to 100 feet.

As it has been observed that during a flood the waters flowing along the transverse bank have an inclination of half that of their bed, this inclination is given to the top, which at the cross wall is at a height of 4 feet 11 inches above the highest flood-level; and at the junction of the longitudinal and transverse banks the tops are 1 foot 8 inches above the highest flood-level, and the longitudinal dyke is sloped down on each side of the junction till at its extremities the top is 3 feet 3 inches below flood-level, to allow the flood waters to flow over into the river, and thus prevent their rising to a dangerous height against the transverse bank. They are 9 feet 10 inches wide at the top, and are widened, where constructed with rubble stone, by a step on each side, about halfway down, which is made 3 feet 3 inches wide in the longitudinal dyke, and 2 feet 6 inches in the transverse bank. The slopes are 1 to 1 on the exposed, and 3 to 2 on the other side. The ⊤ dykes have to be placed opposite each other on each bank of the river, to keep the course straight; and where the inclination of the bed of the Durance is 1 in 333 the dykes must be placed at intervals of from 2,600 to 3,300 feet. Eight dykes have been constructed within a length of 6 miles 4½ furlongs, extending from the commencement of the plain of Portius to the parish of Villelaure, at a total cost of £41,657, of which £30,926 have been contributed by the Boards, £9,870 by the State, and £861 by the Department. The increase in the value of the adjacent lands in consequence of the construction of the embankment is as follows:—

		£.	s.	d.
569	acres of reclaimed land valued at £13 15s. per acre .	7,823	15	0
618	„ land brought into cultivation, having an increased value of £32 8s. per acre . . .	20,023	4	0
2,768	„ preserved from floods, having an increased value of £9 14s. per acre	26,849	12	0
	Total increase in value	54,696	11	0

The works having been only recently completed, the value of the lands benefited is likely to increase, and even according to the above estimate the proprietors have obtained an ample return for their expenditure. The improved value of the land benefits the State by the increase in rates and taxes imposed on them, and in the stamp duties on change of proprietorship; and the remission of taxation on the occurrence of floods is obviated. The State may be reckoned to be already receiving from these sources an increased revenue equal to the interest on a capital of at least £6,450; and if the assessment should be raised to the proper standard the State would probably receive, in the form of additional revenue, a yearly sum equivalent to the interest on the whole amount granted for the works.

L. V. H.

On the Floods of the Seine, and the means of preserving Paris from Inundation. By M. Belgrand.[1]

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1086.)

The great floods of the Seine, which occur at long intervals, rise higher than the level of a considerable portion of the land on which Paris is situated. The following table gives the heights, on the gauge of the bridge of Tournelle, of the greatest floods of the Seine in the present and the last two centuries, and the areas of Paris, within the lines of fortification, and below the levels of the floods, that would be submerged if there were no main sewers along the quays to stop the town sewers from communicating directly with the river.

	Height on Gauge above Datum.	Area of Paris below Flood-level.
	Feet.	Acres.
Flood of 27th February, 1658	115·03	2,881
" 26th December, 1740 . . .	112·04	1,779
" 3rd January, 1802	110·57	1,124

To protect the town from danger of inundation it will be necessary to raise the whole of the quays above the highest flood-level, and to shut off, in time of flood, all communication between the river and the sewers in the middle of the town, and at the same time to remove the contents of these sewers, either by pumping, or by discharging them so far down the river that the rise of the flood in the outlet sewer shall not be high enough to cause inundation. The quays between the bridges of Austerlitz and Jena are above the highest flood-level, and the two main sewers, constructed along these quays, which unite on the right bank of the river, discharge their contents from one outfall situated a little below the bridge of Asnières. Accordingly no flood can occur in Paris between these bridges except by rising from the outfall in the main sewers; and it has been found that in times of great floods the level of the water in the sewers at the bridge of Alma and the Place de la Concorde is the same as at the outfall; and on the 17th of March, 1876, at the height of the flood, it was 7 feet $11\frac{1}{4}$ inches below the level of the river at the Pont Royal, or 96·4 feet above datum, which is lower than any part of Paris. Consequently, if the main sewers were prolonged, together with the quays above flood-level, to the limits of Paris, and intercepted all the sewers, of which some still communicate directly with the Seine, the water in the sewers would never rise, in the highest flood, above 96·4 feet + 7·54 feet = 103·94 feet above datum on the right bank, and 104·33 feet on the left bank, which levels are above the surface-level of only a small portion of the city. By cutting off all communication between the river and the sewers during great floods, and pumping up the sewage by

[1] *Vide* Minutes of Proceedings, vol. xliv., p. 262, and vol. xlv., p. 308.

the 800-HP. engines at Clichy, which are ordinarily used for raising the sewage for agricultural purposes, the whole of Paris might be secured from inundation. The cellars in Paris, of which 3,051 were flooded last March, and some of which in the low parts of the city are submerged during ordinary floods, might be secured against inundation by laying a system of drain-pipes below the cellars, unconnected with the river or the sewers, but connected with sumps, and keeping the water in the sumps at its normal level by the aid of centrifugal pumps, worked by turbines, which could be turned by a stream from the water supply of the town.

L. V. H.

Water Supply of the District of Aix. By M. Oppermann.

(Nouvelles Annales de la Construction, 3rd series, vol. i., pp. 6, 42, and 130, 3 pl., 1 woodcut.)

The town of Aix was authorized, in 1838, to make a canal for obtaining a supply of water from the Durance or the Verdon, and at length, in 1862, a scheme was finally decided on, which was estimated at £351,000, for obtaining water from the latter. The quantity of water to be taken was fixed at 1,320 gallons per second, and where it is drawn from the Verdon a dam, 36 feet high and 138 feet long, has been constructed. The canal crosses the valley of Beaurivet on an aqueduct, 312 feet long, with ten arches; and going through the narrow defiles of the Verdon, a distance of 6 miles 6½ furlongs, it follows the valley till it enters the Maurras tunnel, 2 miles 4½ furlongs in length. After passing through the Malouric valley it crosses the ravine at the bottom on an aqueduct, 49½ feet high, pierces the Ginasservis hill in a tunnel, 3 miles 1½ furlong in length, and is continued in cutting to the valley of St. Paul, which it crosses in two wrought-iron siphons, and then in cutting again to the tunnel of Rians, 467 yards long. The canal next skirts the slopes of the ridge extending from Rians to Meyrargues, traversing the valleys of the Lauvière, Trempasse, and Loubatas in siphons; near Pierrefiche it enters a tunnel, 1 mile 7 furlongs in length, and, after emerging from it, crosses the Parouvière ravine on a bridge, 65 feet high and 398 feet long, and going through the St. Hippolyte tunnel, 1,039 yards long, terminates in the basin which forms the source of the branch canals. The total length of the main canal is 51 miles; its fall is 131 feet; the inclination varies between 1 in 909 and 1 in 4,873; it is greatest in the tunnels (varying between 1 in 909 and 1 in 1,250), so as to increase the velocity of the flow, and consequently allow of a diminution in the sectional area. The depth of water in the canal is 4 feet 11 inches, being increased to 6 feet 6¾ inches in the tunnels. The width of the canal varies in inverse proportion to the inclination, the greatest width being 9 feet 10 inches at the bottom, and 27 feet 10½ inches at the level of the top of the side-banks; in the tunnels it varies between 6 feet 2½ inches and 11 feet. The most important work along the canal

is the siphon in the valley of St. Paul, which was in the first instance tunnelled in the rock and lined with masonry; this siphon, however, was injured for a length of 66 feet when the pressure of water came on it; and it failed a second time after having been repaired. Accordingly, two wrought-iron siphons were substituted for carrying the canal across the valley, this being considered the surest and quickest method of completing the work, the opening of the canal being delayed by the failure of the siphon. The two wrought-iron tubes (5 feet 9¼ inches internal diameter) run at right angles to the line of the valley. They are laid horizontally at the bottom for a distance of 322 feet, and on each side of the centre they have an inclination of 1 in 2·44 and 1 in 2·7, and their lengths are 251 feet and 276 feet respectively. The tubes are fastened at their extremities in masonry supports, forming the sides of basins communicating with the canal. The thickness of the iron plates of the horizontal tubes is 0·354 inch, and of the inclined tubes 0·315 inch, and the greatest strain on any portion of the iron-work is under 3·17 tons on the square inch. The tubes are placed about 3 feet above the ground, on supports 3 feet wide, the clear space between each support being from 31 feet 4 inches to 32 feet 6 inches, except over the ravine, where it is 37 feet 9 inches; and the roads on each side of the ravine have been diverted and raised so as to cross the tubes at right angles on masonry bridges. The canal has been made for the purpose of irrigating the commune of Aix and the neighbouring districts, to afford water power for mills, and for supplying the town of Aix with water. The water power obtainable for industrial purposes from the falls and inclined weirs on the canal is about 2,836 HP.; and it is expected that a great increase in manufactories will result from the enterprise.

The following is a summary of the cost of the canal, giving the expenditure already incurred on the works, and the estimate for completing them:—

EXPENDITURE ON COMPLETED WORKS.

	£.
Earthwork	81,182
Tunnels (14), shafts (4), and galleries (7)	169,025
Bridges and small aqueducts	23,895
Large aqueducts and siphons	39,223
Dam and sluice-gates	35,766
Walls, banks, lining and puddling	49,507
Purchase of land	27,972
Branch canals and trenches	15,900
Plant, machines, pumps, &c.	8,609
Superintendence of works, salaries, &c.	39,153
Office expenses	5,799
Journeys, surveys, and preliminary expenses	7,424
Rate for the supply of water to the canal	414
Law suits	1,821
Interest of 6 per cent. on capital during construction	146,063
Total expenditure on completed works	651,693

ESTIMATED COST OF COMPLETING THE WORKS.

	£.
New siphons in the valley of St. Paul, siphon in the valley of the Arc, the Calèche aqueduct, lining the Maurras tunnel and other works, and land charges for completing the main canal and the branch canals in the Aix district	54,069
Earthwork, bridges, land charges, and indemnities for trenches in the Aix district and branch canals in the adjacent districts	52,000
General expenses, and interest on capital	101,025
Total estimated cost of completing the works	207,094

It is believed that the total expenditure on the works, including all extra work that may be found expedient, will be within £880,000. The cost of the tunnels has varied between £4 13*s.* 2*d.* and £9 14*s.* 9*d.* per lineal yard, according to their length. Their average cost was £6 1*s.* 4*d.*

L. V. H.

The Salzburg Waterworks.

(Journal für Gasbeleuchtung und Wasserversorgung, vol. xix., p. 346.)

Salzburg may be quoted as an instance of a prosperous town making considerable sacrifices to provide hygienic and other public improvements. In a comparatively short time there have been carried out the embankment of the river, the demolition of fortifications, widening of streets, canalisation, the erection of school buildings, bathing establishments, slaughterhouses, and waterworks, which last is considered one of the most beautiful and best of its kind. The water is taken from the powerful and celebrated spring Fürstenbrunn, in a ravine of the Untersberg, known for its marble quarries, about 5½ miles from Salzburg. The municipality had been granted the right to use half its total outflow—624 gallons per minute—which represents a total for the twenty-four hours of 900,000 gallons. Allowing for a population of 25,000 (at present there are only 17,000), this would give about 36 gallons per head, which will compare favourably with that received by other towns, and will be ample. Dr. Max von Pettenkoffer, of Munich, reporting on the excellent quality of the water, expresses his astonishment to find so soft a water in the midst of a chalk formation. By numerous experiments on the air contained in the ground, he came to the conclusion that the quantity of carbonic acid gas, and consequently the quantity of chalk, and the degree of hardness of the water taken from the ground, whether flowing from natural springs or pumped from sunk wells, depends on the quantity of carbonic acid contained in the air of the said ground. And the carbonic acid gas contained in the earth is to a great extent produced by decomposing organic matter. The

reason why the Fürstenbrunn water contains so little chalk must chiefly be that the atmospheric water, which penetrates into this spring from the mountain, does not come much into contact with strata containing decomposing organic substances. This is a guarantee against the introduction of organic germs. In his opinion the town authorities have acted rightly in not distinguishing between water used for drinking and for other purposes, but in insisting on an equal degree of purity for all. It is not only in the human body, but also in dwellings, that the germs of disease contained in water can develop themselves; and he thinks that the latter is most probably the cause of certain epidemics which are often attributed to drinking-water.

Mr. Junker, an engineer from Vienna, was commissioned by the town to make the plans for bringing the Fürstenbrunn to Salzburg. The contract for the construction was taken by the German Waterworks Company of Frankfort on the Main in June 1873.

I. Works at the Source.

These presented some difficulty, on account of considerable occasional swellings in the Fürstenbrunn, the outflow sometimes increasing to 12 cubic feet per second. The town supply is carried by a canal cut out of the rock from the facing of the opening to the so-called pressure chamber, from which a cast-iron pipe leads into the town, a penstock in the canal regulating the quantity of water which flows into the pressure chamber. The latter is built in two parts separated by a weir. The first part receives the water from the canal, a waste-pipe being provided to turn it back into the brook when not required. When this pipe is closed, the water passes over the weir into the second part, and thence to the town. The overfall serves as a simple and easy measurement.

II. Main to the High-pressure Reservoir on the Mönchsberg.

The Untersberg, which descends precipitously, is the last mountain in the chain in that direction. From this point northwards extends a valley, from which the isolated conglomerate rocks of Salzburg project. One of these, the Mönchsberg, was chosen for the high-pressure reservoir, the water to be led to it by pipes. As the direct road would have had to pass almost entirely over swampy land unsafe for the foundations of a conduit, more suitable ground was sought. The main now makes a rapid descent into the valley, follows the contour of the ground, the rise and fall being but slight till it reaches the town, where it ascends again in an equally rapid manner to the reservoir on the Mönchsberg. As no suitable spot could be found on the slope it had to be placed on the top, whereby, though the pressure in the distributing pipes became considerable, the advantage was gained of being able to supply the houses on the hill. The height of the source allowed the high-pressure reservoir water-level to

be fixed at 264 feet above the zero point of the Salzach at the town bridge, the height of the town being from 26 to 39 feet.

The lowest water-level of the spring is 577 feet above the same point, and that in the pressure chamber was fixed at 573 feet. The pressure available to overcome the friction in the main pipes is accordingly 309 feet. The total length of the main line of pipes is 10,061 yards ($5\frac{3}{4}$ miles), and the quantity of water delivered per second is 10·4 gallons.

These conditions render a diameter of 8·85 inches advisable for the main pipe, with a velocity of 3·9 feet, and according to Weisbach's formula a capacity of 11·15 gallons.

The main pipes were made of cast iron with spigot and faucet joints. The pressure in them varied from 8 atmospheres (120 lbs. on the square inch) to 16·5 atmospheres ($247\frac{1}{2}$ lbs.), when the outlets were closed, which rendered special care necessary in the selection of the material and in manufacture. Pipes of three different thicknesses, according to the pressure, were all tested in the factory and at Salzburg, the strongest being subjected to a pressure of 33 atmospheres, the next to 26, and the weakest to 20 atmospheres (495, 390 and 300 lbs. respectively). The corresponding thicknesses of the metal are 0·433, 0·394, and 0·354 inch (11, 10, and 9 millimètres).

There are in the main conduit five high and six low points; air-valves have been placed at the former, and drains for emptying and cleaning at the latter; so that by occasional opening of these outlets all air and foreign matter can be removed. Self-acting air-valves were not considered reliable. The chief use of the air-valve is to get rid of the air in filling the main, and in this the working is very simple. All valves are first opened, and each closed as soon as water appears. The valve-spindle is of gun-metal. By screwing this down a disc of india-rubber is pressed tightly on to an opening 0·59 inch in diameter, and the whole is placed on a cast-iron stand-pipe which rises vertically from the main. The opening in the drain-pipe is 4·75 inches in diameter. Stop-cocks are usually inserted in the main pipes at these places, and these, like the air-valves, are inclosed in brickwork, so as to make them easily accessible. The main was laid at a depth of 5 feet under ground.

III. The Reservoirs.

The position of the town between two hills, the Mönchsberg and the Kapuzinerberg, rendered it possible to supply the network of pipes from two reservoirs, one on each summit. Their capacity was calculated on the supposition that two-thirds of the daily consumption of 900,000 gallons spread over sixteen hours would be supplied by the main pipes, the remainder to come from the reservoirs. As the greater part of the town is situated near the Mönchsberg its reservoir was designed for 220,000 gallons, the remainder being supplied by the counter reservoir with a capacity of 121,000 gallons.

The length of the main reservoir was fixed at 164 feet, its breadth at 26 feet. This great length was determined upon because the summit of the mountain consisted of solid conglomerate rock, and had to be cut through under any circumstances, so that it was found advantageous to utilise the space, as the blasting or tunnelling for a line of pipes would otherwise have added considerably to the expense. The high-water level was fixed at 9·8 feet, the space being divided lengthways by a wall, which serves also for a springing of the arch covering each half. Each of these two divisions is connected on one side with the conduit from the source, on the other with the main supply pipe, penstocks being provided to cut off the connection with either. As the water enters and leaves the reservoir at opposite ends, there is always a constant motion, and it is impossible for it to become stagnant. All valves, penstocks, &c., can be conveniently opened and closed in a house placed at either end, and there is no ironwork in the interior of the reservoir.

The counter reservoir on the Kapuzinerberg was carried out in a slightly different manner. The side of the hill on which it had to be built was a precipitous wall of hard rock, and the necessary space had to be obtained by blasting. A gallery, 28·2 feet broad, 16·5 feet high, and 65·7 feet long, was thus made; and, like the other hill, the rock was found so compact that it was only requisite to close in the front, to make an even flooring with bricks, and to cover the inner surfaces with a coating of cement.

In order to prevent the water from becoming stagnant, and to keep up a constant flow, although it enters and leaves by the same line of pipes, the interior space was divided by a wall into two equal parts joined together at the inner end only. The water-pipe, before it reaches the reservoir is divided into two branches, one being connected with each chamber; and by putting in two flap-valves, which open in different directions, it was arranged that the only entry for the water should be at the beginning of the first chamber, and its only exit at the end of the second one, thus insuring a constant flow through both chambers.

The construction of this reservoir was attended with great difficulties; the site could only be reached by circuitous footpaths, and an almost perpendicular scaffold had to be erected against the side of the rock for drawing up the materials. Its highest water-level was fixed at 236 feet above zero.

IV.—The Distributing Pipes.

A main line of pipes, from the high reservoir on the Mönchsberg, passes through the middle of the town, and crossing the Salzach by the bridge, mounts by the Linzer gate on the right bank to the counter reservoir. From this main on either side branches lead to different parts of the town. The diameter of the pipes from the Mönchsberg was fixed at 11·8 inches, and that from the Kapuzinerberg at 5·9 inches. The other pipes have diameters of

9·8, 7·8, 5·9, 4·7, 3·9, and 3·1 inches. The network was so arranged that the circulation in short pieces could be cut off without interfering with the water supply of adjoining streets.

The main pipes from both reservoirs had in certain parts to be carried down the vertical wall of rock. In these cases flanged pipes were used. They were bolted together and supported by a cast-iron base, having a broad bearing surface. The pipes were then boxed in with a construction of iron and wood, the inner space of which was filled with a non-conductor of heat.

Cast-iron boxes, surrounded by brickwork, were placed at the chief crossing places. These boxes have four outlets for the different branches, with taps. On the top of each box is an air-valve, and at the bottom an outlet leading to the drains.

The pipes are laid at an average depth of 4·9 feet, care having been taken that they should all slope towards one of the drains placed at the lowest points.

The network of pipes is composed as follows:—

1,050	feet of pipe with diameter of	11·8 inches.
1,090	,, ,, ,,	9·8 ,,
3,675	,, ,, ,,	5·9 ,,
1,792	,, ,, ,,	4·7 ,,
7,220	,, ,, ,,	3·9 ,,
29,226	,, ,, ,,	3·1 ,,
44,053 feet.		

4 boxes; 54 stop-valves; 109 hydrants.

A store-place was fitted up close to the railway station, with a line of rails leading into it, so that the pipes could be stored without being previously unloaded. The pipes were asphalted in the factory on the system of Dr. Angus Smith. The work was commenced on the 15th of May, 1874. The water from the spring was admitted into the high reservoir on the Mönchsberg on the 24th of November of the same year, and into the branch pipes on the 26th of July, 1875. On the 31st of October, 1875, the works were so nearly finished that they were inaugurated and handed over to the town.

The Paper is accompanied by a series of drawings illustrating the reservoirs, distribution of pipes, valves, &c.

W. W.

The Upsala Waterworks.

By J. G. Richert, and Nydquist and Holm.[1]

(Ingeniörs-Föreningens Forhandlingar, vol. xi., p. 3.)

The city of Upsala covers an area of about 400 acres, being nearly a rectangle of 4,000 feet square. It is divided into two

[1] There are two communications; in the first the reservoirs and distributing works are described, and in the second the pumping machinery.

nearly equal parts by the river Fyrison; the eastern side, which comprises most of the newer buildings and the railway station, is nearly level, while the cathedral, university, and other public buildings are situated on the western bank on rising ground, which attains a height of about 150 feet. The greater part of the city is laid out in rectangular blocks about 400 feet square, every one of which is to be provided with a circumscribing supply main under constant pressure, having a fire hydrant at each corner. The supply is taken from the St. Eric's spring, on the west bank of the river, by an 8-inch cast-iron pipe leading to the pumping-station on the river at Islandsbronn on the same side, water power being used, with an auxiliary steam-engine in the event of an extra supply being required for fire service or during low-water in the river. From the pumping engines, a 10-inch pipe passes east for about 300 yards, where an 8-inch main commences, which makes a circuit of about 1½ mile through the centre of the town, passing under the river by a siphon, back to a 10-inch pipe communicating directly with the reservoir. From this main branch, services, 4 inches in diameter, are taken off at every side street, the whole circuit being divided into nine districts.

The reservoir for ordinary service is situated in the grounds of the castle, about 143 feet above the low-water level of the river. It is open, circular, 21 feet deep, with an average diameter of 52 feet within the ring wall of masonry, which is puddled at the back. The bottom is of concrete upon a puddled bed. In order to obtain an increased pressure for fire service, the reservoir is in communication with an 8-inch standpipe built into the wall of the castle, about 60 feet high, bringing the head up to 200 feet above low water. The head of water available for quenching fire, is computed at about one-half of the effective hydrostatic head at the hydrant, which, with a discharge of 1 cubic foot per second, throws a jet of from 105 to 118 feet over the eastern or lower side of the town, and about 100 feet over the greater part of the upper town, except that nearest the reservoir. With the discharge increased to 2 cubic feet, the height is about 15 feet less, in both cases the pressure being taken from the reservoir. Under these conditions about three-quarters of the area of the town would be protected, the highest houses not exceeding 60 feet. When the standpipe is brought into use, with a load on the pump equal to a head of 210 feet, and a discharge of 2 cubic feet per second, the effective height is from 150 to 170 feet in the lower, and from 106 to 150 feet in the upper town. The principal source of supply at the St. Eric's springs not being equal to the larger demand, provision is made for a secondary supply from the springs supplying the castle reservoir dam.

The pumping machinery, made by the Trollhätten machine works, consists of four horizontal double-acting force pumps, 12 inches in diameter and with 2 feet stroke. One pair is arranged to be driven by water, and the other by steam power, but both discharge into common suction and pressure air-vessels. The water power is

furnished by a radial double turbine, *i.e.*, having a vertical axle and horizontal guide sluice apparatus, receiving the water from the external circumference. The turbine is double in the sense of being divided into two wheels of unequal size, but both 10 feet in diameter, which can be brought into use together or separately according to the level of the river, which varies about 7 feet. The smaller wheel, being below, is used during low water. The pumps on the turbine side are driven without spur gearing, being connected directly with a disc crank on the top of the shaft. Generally one pump only is used, the other being kept in reserve, but both can be worked when there is water enough to drive the two wheels. On the steam side the pumps are driven by spur gearing from a horizontal non-condensing engine with jacketed cylinder and variable expansion gear, on Meyer's principle. The turbine and steam-engine have been designed by C. A. Ångstrom, and the pumps and boiler by Messrs. Nydquist and Holm, the Authors of the second memoir.

H. B.

The Vienna Water Supply.

Report by A. Aird, Aug. Fölsch and Prof. R. von Grimburg.

(Journal für Gasbeleuchtung und Wasserversorgung, vol. xviii., p. 812.)

The three referees who were instructed to report upon the means for insuring a constant water supply for Vienna, after a careful examination of the various plans and localities, commence by stating that the necessity for a report arose chiefly from a succession of failures of the 33-inch and 36-inch pipe-lines, which, in spite of the assistance obtained by resorting to the older "Kaiser Ferdinand" Works, resulted in awkward and dangerous interruptions of the service. That these failures were rightly ascribed to defective workmanship in the laying of the pipes, and to hidden faults in the castings, was shown by the repairs rendered necessary by the frequent bursts, while it was also remarked that the failures occurred almost exclusively on those lines in which "thin pipes" were used, *i.e.*, pipes of the thickness originally specified, before it was decided to increase the standard. The report gives examples of failures in these thin pipes, showing clearly the small degree of security they afford, even under low pressures.

To attain a connection between the reservoirs on the Rosenhügel and on the Wienerberg respectively not liable to interruption, the authorities had proposed the construction of a new line of 33-inch pipes. The existing line, of 36-inch and 33-inch pipes, consists chiefly of "thin pipes," supported in some places on a bed of concrete. The report points out the great risk to which the supply is exposed by the use of these thin pipes. Although concrete secures a firm and even bedding, in the event of a rupture

the restoration of the line by the changing of single pipes is rendered more difficult and tedious by the fact of the oxidised iron entering into an intimate combination with the concrete. Allusion is also made to the general experience, confirmed in Vienna, that interruptions to water supply do not come singly, and that provision must be made for a succession of interruptions, especially as in Vienna most houses have either small cisterns or are without them. The line above mentioned and others discussed in the report are therefore proposed. Further, the amended thickness of $1\frac{1}{2}$ inch for the 36-inch pipes, fixed upon by the Commission of Experts of 1871, is now recommended to be increased to at least $1\frac{1}{12}$ inch. Reference is made to the danger of relying for the water supply of a large town upon the service through one main line only, and the question of a further main line of 36-inch pipes, costing at least £100,000, or of an aqueduct, costing even more, is next discussed, and in view of this heavy expenditure alternative lines have been considered by the referees, the result being that they recommended the adoption of one of the latter.

With respect to the complaints as to the quality of the water, in spite of its excellent character, the report alludes to the instances in which the same result has arisen from insufficient circulation of the water in the pipes, owing to the consumption not having attained extensive dimensions, and the referees are also of opinion that in many such instances the defective arrangement of the internal fittings has much to do with the unsatisfactory accounts of the water. They recommend the abolition of "dead ends" wherever practicable, by the construction of junction lines, no matter how small in diameter.

The sluice-cocks of the Vienna water supply are not, as usual, placed simply in the ground, but each sluice-valve, from 3 to 36 inches in diameter, is placed in a special brickwork chamber, closed at the top by a double cover. To open or close the valve it is not only necessary to open the covers, but it must also be ascertained whether or not the chamber is filled with carbonic acid gas or illuminating gas, as if so, an exhauster has to be applied before the valve can be manipulated. The dangers of this system are strongly commented upon, and for all future lines the adoption of valves without chambers is recommended, and where in existence it is proposed to gradually remove those of the numerous small sizes, and to ventilate the remaining chambers by down pipes.

The question of reservoir capacity also engaged the attention of the referees. At the date of their report (October 1875) the aggregate capacity of the four existing reservoirs was 908,500 cubic feet. Under the most favourable conditions this amount is insufficient, and the smallest total storage capacity which the referees recommend is 2,244,000 cubic feet, being an additional storage of 1,315,800 cubic feet.

So long ago as 1864, the Commission estimated the daily requirements of the then population of Vienna at 2,364,000 cubic feet,

2,244,000 cubic feet per day being required even in the winter months; but observations on the total supply of the new works from October 1, 1873, to October 12, 1875, *i.e.*, for 742 days, have shown that the supply varied from less than 2,364,000 cubic feet on 454 days, or six-tenths of that period, to only 1,020,000 cubic feet on 60 days. A comparison of these figures with the actual requirements of the smaller population eleven years ago leads the referees to the opinion, that it is high time to provide additional sources of supply, especially as the demand for water is increasing, as is shown by the circumstance that there were, at the date of the report, 3,862 connections with the mains, as against 1,718 in 1874. The referees point out the disproportion between the gross cost of the works and the minimum quantity of water which they are capable of supplying, and recommend the commencement of trial works for the discovery of further supplies. The cost of one such trial proposed, at the Fuchspass Springs, is estimated at £5,000, and will require two years and a half for completion, after which a further period of one year would be required for gaugings and observations, so that no less than three years and a half must necessarily elapse before a decision can be arrived at as to the definite carrying out of the works, costing probably £50,000, and requiring two years for their execution.

The referees also had before them particulars of a scheme for obtaining additional supplies from other springs, such as the Alta-quelle, by driving an adit 24 feet beneath their level, thus involving a deep conduit for the upper part of the new supply line, in difficult ground. The referees propose to obviate this by taking the supply at those points from which the water of the Steinfeld district runs to the Alta springs. The tapping of springs at their exit from the hills has resulted everywhere in a marked diminution of the volume, and in many cases not one-half the quantity originally calculated as the minimum supply has been collected. The report describes the characteristics of the district, the volume of water permanently moving under the Steinfeld being so great that the abstraction of even the whole supply of Vienna, distributed among various points, would effect no perceptible diminution of the ground-water below. It is therefore recommended that a well be sunk and that powerful engines pump the water continuously for several months, during the low state of the springs. A decision could then be arrived at whether the permanent works for the additional supply to the town should consist of collecting conduits with natural fall, or whether engine-pumping power should be adopted, the chief advantage afforded by the latter mode being the possibility of lowering the well and increasing the lift in case the level of the water should eventually sink, while the expense of lowering the collecting conduits would be enormous.

The report adds that the preliminary works recommended could be arranged so as to give a decisive result within a year.

J. S. H.

Experiments with Water-meters at Wiesbaden.

By C. Muchall, Engineer of the Wiesbaden Gas and Water Works.

(Journal für Gasbeleuchtung, vol. xix., p. 236.)

After commenting on the great importance of water-meters for German towns, the Author points out the practical results from the trials of a large number of meters, in contradistinction to many experiments, lately published, with a single instrument of one particular system, which are almost useless, as they do not indicate how the meter acts in practice, to what accidents it is liable, and what is the cost of maintenance and repair, questions which can only be settled by long experience, but on which much of the accuracy depends. Although that meter is preferable which measures most accurately and the smallest quantities, no system of meters can ever come into general use in which the cost of fixing, maintenance, and repairs is large.

The four systems of water-meters used were those of Kennedy, Frost, Siemens, and Tylor, the two former being piston meters, and the two latter wheel meters.

The numbers of each on the 31st December, 1875, were as follows:—

Calibre.	$\frac{3}{8}$ inch.	$\frac{1}{2}$ inch.	$\frac{3}{4}$ inch.	1 inch.	$1\frac{1}{2}$ inch.	2 inch.	4 inch.	Total.
Kennedy . . .	42	53	7	8	..	..	..	110
Frost	21	3	..	..	..	..	..	24
Siemens . . .	11	258	886	36	5	3	1	1,200
Tylor	..	152	158	..	..	..	..	310
	74	466	1,051	44	5	3	1	1,644

The points to be taken into consideration were: 1. Degree of accuracy of the meter; 2. Duration of the initial accuracy; 3. Frequency of repairs; 4. Facility of fixing and removal; 5. Cost of purchase and maintenance.

Those of Kennedy and Frost were found to be most accurate; that of Tylor generally registered 2 to 3 pints per minute, while the Siemens meter would with a small flow either not register at all, or only very slightly.

Each meter was tried, before being used, with a Kennedy and a Frost meter known to be correct, and from time to time gauged by a measuring vessel of known contents. Both the entry and the outflow pipes were provided with cocks, that of the former being always wide open, to have the full pressure on the meter.

The outflow cock served to regulate the volume of water which flowed through. The trials were usually carried out by allowing 1,100 gallons to flow through in quantities varying from 7 to 35 pints per minute. If the differences at the end of the trial were greater than ± 3 or 4 per cent., the meter in question was adjusted and tested as before. This adjustment only took place with the wheel meters, as the piston meters always registered correctly when the piston was properly packed. The adjustment was effected either by slightly extending the blades of the fan, so as to make them travel more quickly, or by filing them down to diminish their speed, or else a counter stream was more or less increased, for which purpose the Tylor meter is provided with a set-screw, whereas the Siemens meter must be taken to pieces in order to be adjusted. It was found, however, that the latter adjustment was not accurate, as the influence of the counter stream on different volumes of water, passing through in the same time, was not the same.

The duration of the initial accuracy depends chiefly on the construction. The Frost and Kennedy meters registered accurately only so long as the piston packing and gearing were perfect. Kennedy meters were often found inaccurate on account of the india-rubber ring becoming concave. In this respect the wheel meters are to be preferred. It was found, especially of the Siemens meters which have been several years in use, that some showed as much as 20 per cent. plus, and others a considerable minus. In both cases the variation may be attributed to rust, deposited either on the blades of the fan or on the axle. In the first instance this would increase both the surface of the fan-blade and its mass, and thereby have a tendency to increase its velocity, especially in the case of an irregular flow; whilst, if the rust is on the axle, the increased friction on the bearings would diminish the speed. It was also found that the same meter, after it had been cleaned from rust, registered less if the rust had been on the blades, but more if it was removed from the axle. Tylor meters, which did not exhibit similar inaccuracy, were also quite free from rust, so that meters whose casing consists of brass must be preferred to those of iron.

With regard to the frequency of repair, this is usually necessitated by their ceasing to work, but occasionally by leakages, illegibility of the dial, or damages. The latter causes are comparatively rare, and can never be totally avoided, but it is different when a meter stops working, which is essentially caused by a fault of construction. It appeared that Kennedy meters ceased to register when either the stuffing-box of the piston-rod or that of the valve-rod (steuerrungshahn) was tightened too much, or when the packing became hard and dry. With the heavy pressure, sometimes 8½ atmospheres, this cannot always be avoided. It also failed when the india-rubber ring, which rolls up and down on the piston, got twisted or broken.

Of all the meters observed, those of Frost stuck most easily,

as the complicated gearing, which is in the water, is soon covered with slime and ceases to work. As all stagnant water deposits slime, however slightly, the frequent stopping of this meter is a great evil, and it is rendered the more inconvenient because the meter, when fast, does not permit the water to pass.

In Siemens meters the cause of stoppage is usually slime and rust, either on the axle or on the wheel, or else deposited between the wheel and the casing.

With Tylor meters there have been several instances in which two or more of the fans have been broken off the wheel. This is partly caused by the brittleness of the metal of which they were made (since replaced by tougher metal), but more frequently by the presence of foreign substances, such as small pieces of lead or tin too fine for the meshes of the sieve, which caused the fan-wheel to jam, generally the result of careless soldering and repair; these may be kept back by the sieve for a long time, and though not bigger than the head of a small pin, may at length suffice to stop the meter.

Of the sixteen hundred and forty-four meters fixed up to the end of 1875, one hundred and ninety-five stuck in the course of that year. They were—

—	Total Meters.	Total Stopped.	Per-centage.	Cause of Stoppage.			
				Broken Piston-ring.	Gearing clogged.	Rust in Meter.	Tin between Fan and Case.
Kennedy .	110	50	45	10=9 %	40=36 %	..	..
Frost . .	24	2	8	..	2=8 %	..	..
Siemens .	1,200	128	11	..	..	68=6 %	60=5 %
Tylor . .	310	16	5	..	..	..	16=5 %
	1,644	196	..	10	42	68	76

All these had to be taken out excepting the majority of the Kennedy meters, in which the gearing had become clogged. If in the two latter, allowance be made for stoppages caused by tin between valve and case, as not properly depending on the construction of the meter, there remain 6 per cent. of stoppages with Siemens meters, and none with Tylor.

Besides these stoppages, and the repairs rendered necessary by them, one hundred and thirty-five meters, or about 8 per cent., required slight repairs, such as leakages in the stuffing-boxes, replacing dials, glasses, padlocks, &c., in which the meter rarely required to be changed. To complete the list it must be added that thirty were damaged by frost.

In respect of facility of repair and removal the Kennedy meter is the least handy from its size and weight. The others only need one

workman to fix them, but the Kennedy and the largest size of the Frost meters require two. Tylor and Siemens meters are in this respect nearly equal, but the Tylor meters are somewhat cheaper to fix than those of Siemens, as no soldering is required.

The piston meters are so much more expensive than the others, that on this ground alone they are never likely to come into general use. For example, a ¾-inch piston meter by Kennedy costs about three times as much as a ¾-inch Siemens or Tylor meter, and a ½-inch costs twice as much. This proportion should not form the basis of a comparison, as through meters of equal diameters but different systems the maximum flow is not equal, the proportion of water passing through the ¾-inch and ½-inch meters of Kennedy, Tylor, Siemens, being about 100 : 65 : 60.

With a pressure of 75 mètres (246 feet) the maximum flow would be as follows:—

System.	1 inch.	¾ inch.	½ inch.
	Maximum flow in gallons per minute.		
Kennedy. . . .	70·2	37·2	22·0
Tylor.	..	24·1	14·1
Siemens	48·2	23·0	13·1

These results are too small for Kennedy meters, for as the resistance in the pipes increases with the velocity, it is incorrect to take the calibre given by the manufacturer as the standard of comparison. Both with regard to cost and to calibre for pipes of a certain size, only meters of equal performance can be compared. Moreover, with a normal consumption, the gain in accuracy is not so great as to render a considerable addition to the cost advisable, for with thousands of meters any slight errors in some would probably be balanced in others.

As to the cost of maintenance, the above percentages cannot fairly be compared, as the meters of Kennedy and Siemens have had the most wear; but there can be little doubt that the cost of maintenance with the Kennedy meter is by far the greatest, and that Siemens meters do not seem to be so favourable as those of Tylor. As the latter is made of brass, stoppages caused by rust are not to be dreaded, whilst as the former consists almost entirely of iron, this cause of stoppage will continue until the iron be changed for brass. Rust brought in from the cast-iron street pipes is of no importance, as with well-tarred pipes the formation of rust is very slow. But even if any finely-divided rust does pass through, the best proof that it does not injure the meter is that none has ever yet been found in the Tylor meters. It is pro-

bable that the union of iron and brass under water favours the formation of rust in the Siemens meters.

With regard to damage by frost, in the Kennedy meters the cylinder always bursts; in those of Siemens part of the casing also gave way, and the indicator was pressed out of place; whilst in the Tylor meters no part had burst, the indicator only had been pressed out of place, and the soldering of the casing had come undone, so that the repairs to the latter cost less than those to the other two systems.

On comparing the results obtained from the four systems, the piston meters were not recommended for use in private houses, for, constructed as they are at present, the advantage of greater exactitude in measuring is more than counteracted by the increased cost of purchase and maintenance.

For house purposes the wheel meters of Siemens, or still better, those of Tylor, are more serviceable.

W. W.

On the Use of Chloride of Calcium in the Watering of Public Thoroughfares. By A. Houzeau.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1507.)

The Author long since called attention, in his course of lectures, to the possible utilisation of important quantities of chloride of calcium lost in the manufacture of pyroligneous acid, chiefly in the neighbourhood of Rouen. This utilisation has been effected for some years in the watering of the principal streets of Rouen, and its extension to the streets of Paris is proposed. Watering with chloride impregnates the soil with hygrometric matter, so that it maintains its humidity for a week. The economy over watering with water only is 30 per cent. The use of chloride of calcium further results in coating the earth with a concreted matter of 0·04 to 0·08 inch in depth, which possesses considerable resistance. In practice it has been found that, on a road 1 mile in length by 16 feet in width, 5,630 gallons of water were necessary daily, but that the same result was attained with 1,480 gallons of chloride solution of a strength marking 33° Beaumé, and costing about ½*d.* per gallon, the humectation remaining good for five or six days with the solution of chloride. With water only, 3,520 gallons were expended in 1 kilomètre (1,093 yards) in four rounds daily, the cost being 48*s.* per day; with chloride of calcium, the cost was 32*s.* per day.

P. H.

The Drainage of Stuttgart. By Dr. v. Hack.

(Zeitschrift des Vereins für Baukunde, Würtemberg, 1876, p. 1.)

At the request of Dr. von Hack, Mayor of Stuttgart, a commission was appointed by the Würtemberg Engineer Society, to examine and report upon the project prepared by Mr. Gordon, M. Inst. C.E., of Frankfort, for the sewerage of Stuttgart, including the districts of Haslach and Berg. A report was consequently presented in May 1876, the Medical Society having in the meanwhile declared that from a medical point of view there were no objections to the proposed scheme.

It was proposed to divide the sewerage works into three systems (two upper and one lower), which involved a complete departure from the system hitherto adopted, of carrying the sewers by the shortest route to the existing main collecting sewer, a partially covered watercourse, called the Nesenbach, with which many of these sewers form right-angled junctions. The objections to the use of the Nesenbach were that the invert is imperfect in form and of unsuitable material (sandstone); that in places it is too high to permit sewers running into it at a sufficient depth to drain the adjacent cellars; that flushing is almost impossible; that an alteration of the level and section would be too costly, whilst the sewers of the major part of the upper north-west district of the town could not be carried by the shortest way into the Nesenbach on account of the ridge which intervenes, so that another large main sewer would in any case be required; and, lastly, that the course of the Nesenbach would be too long to properly carry off all the sewage.

The Nesenbach will therefore in future only be used for the rain and house water, which still forms the greater part of the refuse liquid.

The Commission attached great importance to an accurate statement of the rainfall, as upon this point the size and cost of the sewers mainly depend, but they deprecated the system of trusting implicitly observations of rainfall which do not record the duration and volume of individual falls, and recommend that in future more frequent and accurate rainfall observations be taken, and that gaugings of the existing watercourses, with especial reference to the percentage of rainfall carried off by them, be at once instituted. For the general district a rainfall of 0·0487 inch per hour was calculated to amount to a discharge of 76·34 gallons per second from an area of 247 acres. For the Vogelsang a rainfall of 0·176 inch per hour was deemed equivalent to a discharge of 275 gallons per second from the same area, whereas the Commission, for greater safety, recommended the raising of the latter figure to 330 gallons per second; only 27½ per cent. of the total rainfall need be provided.

With respect to the gradients of the sewers, the Commission quote various continental authorities, such as Bürkli and Hobrecht, to show that flat gradients are in many cases preferable, Hobrecht being of opinion that it is better to have a sewer flat than to have the bottom of it drained perfectly dry by a too rapid fall.

The street gullies are to be provided with sludge-retainers and water-traps. The addition to the sludge-retainers of an iron vessel (sludge-box) provided with small openings to admit of the escape of the liquids and the retention of the sludge, and further to admit of the more easy removal of the latter, is to be recommended, as is also a hopper under the street grating to convey the liquid into the sludge-box, to be modified by adopting an arrangement of Bürkli in Zurich, which is elliptical in plan, the body being of cement.

With regard to the materials proposed, the sandstone of the district is not recommended, on account of its non-resistance to the action of the sewer liquids, and on account of its softness, which required the walls of the sewers to be unusually thick in proportion to their size. For their sewer bottoms stoneware invert blocks were decided on; the side walls and arches of the sewers were to be of brick; but inasmuch as bricks of the requisite quality, *i.e.*, free from chalk or lime, cannot be obtained in the neighbourhood, and would therefore involve great expense, a partial use of concrete was recommended. The inner portion of the lower half of the sewers was to be in brickwork, to withstand the scouring action of the sewage.

The question of house drainage mainly followed the principles laid down by Mr. Gordon, that the level of the street sewers should be from 9 to 13 feet under the streets.

As regards the disposal of the sewage, Mr. Gordon stated, and he was borne out by Hobrecht, that the addition of the excreta, &c., to the volume of the sewage need exercise no influence upon the size of the sewers. The Commission estimate that with a water supply of about 20 gallons per head per day the fæcal matters of the population will only amount to 1 in 540 of the whole, or, when mixed with the refuse liquids from factories and with the rain-water, to only 1 in 1,000, and they do not therefore apprehend any ill results from the discharge of the sewage of the lower system into the Neckar. The main sewer of this system would enter the Neckar below Cannstatt, a town of 22,000 inhabitants, which pollutes the river with sewage and the refuse of many factories. The Commission estimate that the fæcal matters of their system would amount to only 6·5 cubic yards per day, the daily flow of the Neckar being 1,356,200 cubic yards, so that these fæcal matters, irrespective even of the water supply, would form only 1 part in 200,000 of the volume of the river.

J. S. H.

On the Manufacture and Durability of the Steel-headed Rails adopted on the Bavarian State Railways. By Adolf Grau.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiii., p. 10.)

The suitability of Bessemer steel for the manufacture of rails was investigated at the Conference of German Railway Engineers, held at Düsseldorf, in September 1874, the conclusion being that, although in most respects admirably adapted for the purpose, no method had yet been devised for counteracting the tendency of these rails to occasional sudden rupture.

After referring to a treatise by Herr Windscheid, describing the results obtained with the steel rails laid on the Cöln-Minden railway in 1867, which were generally satisfactory, and also to an article by A. Petzholdt and H. von Waldegg on the subject of steel-headed rails, as manufactured at the Queen Mary Works, Zwickau, since the year 1867, and laid on the Saxon State railways, the Author proceeds to describe his own experience of steel-headed or compound rails manufactured under his superintendence since the autumn of 1868, at the then newly-erected Maximilian Works at Haidhof, and the first of which were laid on the München, Augsburg and Bamberg railway in 1869.

During the year 1874, blast furnaces, erected at Kamsdorf, Thuringia, in connection with the Maximilian works, were blown in, and from thence the supply of crude iron for Bessemer steel is obtained; before that time the iron used for the purpose was either of best English hæmatite pig, or that of the Osnabrück, Niederschelden, and Styrian districts, the process of conversion being partially regulated by the spectroscope.

The rail-pile, after heating, is hammered, reheated, rolled into the finished rail, and sawn to the desired length. From twelve to twenty of the rail-ends, thus cut off, are each day tested by doubling under the steam hammer (seldom effected without signs of fracture); others, again, are subjected to the test of a weight of 11 cwt. (10 centners), falling freely through a distance of 9·84 feet, the points of support of the rail under trial being 3·28 feet apart, the limit of depression for that distance being fixed at 5·9 inches; and in all cases this has been satisfactorily borne.

The arrangement of steel and iron in the pile, as adopted soon after commencing the manufacture, is shown in Fig. 1, where

B represents the head-plate of Bessemer steel;
S, bars of crude ductile iron;
R, tough fibrous iron;
F, ductile scrap-iron.

The bars shown in position on each side of the steel head-plate were so placed with the design of preventing the burning of the former; but this arrangement was, in 1871, discontinued, it being found that, in the process of rolling, these protection plates generally were extended too far up the sides of the rail-head (see

Fig. 2), and when subjected to traffic separated from and were stripped off the steel portion, although no accident occurred through this.

Fig. 1.

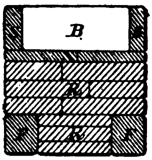


Fig. 2.

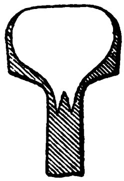
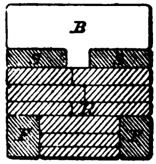


Fig. 3.



The rails, which were rolled from this form of pile in the years 1869–70, failed to the extent of from 1 to 2 per cent. of the total production. In 1871, however, there were only a few instances, and since then the rails have been totally exempt. Where it occurred the separation of the steel from the iron proceeded so gradually as to render the withdrawal of the rails unnecessary until six months after the first signs of weakness had appeared. The rails manufactured in 1871 were, however, subject to another form of failure, which first presented itself in the shape of dark-coloured streaks, extending from the rail-end along the head, developing into cracks of from 3 to 6·5 feet in length, followed by partial breaking-up of the surface. This was attributed to the unsuitable quality of the steel, and might probably have been avoided by a more careful conduct of the conversion process and testing of the surplus rail-ends.

The absolute ruptures were few. The Author is aware of only nine instances; in each case they took place at the fish-bolt holes, which are of rather large dimensions, viz., 1·46 inch by 0·98 inch, the outer hole being 1·12 inch from the rail-end.

In 1871 the form of the steel head-plate was modified, it being rolled with a projection on the under surface, to insure better combination with the iron portion of the rail, and this form has been adhered to up to the present time. In Fig. 3, B represents the steel head-plate; S, bars of crude ductile iron; R, pieces of old rails; F, ductile scrap-iron.

During the last two years rolls have been erected for the special purpose of separating the steel and iron in surplus rail-ends, the steel being returned to the crucible, whilst the web is cut from the foot, and both are utilised in making up the new piles.

As regards resistance to wear, the head of the compound differs slightly from that of the steel rail, in that the former must be composed of metal of a softer and more weldable character (to insure combination with the iron) than is necessary for rails made entirely of steel.

The following table shows the amount of wear of the compound rails, measured at their mid-length:—

Year of manufacture.	Amount of wear. Inch.		Millimètre.
1869	0·039	or	1·0
1870	0·047	„	1·2
1871	0·019	„	0·5
1872	0·019	„	0·5

The experimental steel rails laid on the Cöln-Minden railway, after being subjected to ten years' traffic, show an amount of wear of from 0·08 inch to 0·12 inch.

The quantity of steel-headed rails originally delivered to, and the proportion of the same requiring renewal on the Bavarian State railways, including all the cases of failure already described, is shown in the following table:—

	Original delivery. Tons.	Renewals. Tons.	Percentage.
1869	1,393	124	9·00
1870	1,797	61	3·40
1871	2,807	141	5·00
1872	4,802	1	0·03
1873	3,917	..	..
Total	14,716	327	2·23

If the first delivery of rails in 1869 be omitted from consideration in the above table, there will remain 13,324 tons delivered as against 203 tons, or only 1·5 per cent., of renewals.

Similar steel-headed rails were also laid on the East Bavarian railway, in the year 1869, at places where the gradients are 1 in 100, and the curves of 14½ to 26 chains radius, the percentage of renewals up to the end of the year 1873 being as follows:—

1869	0·60 per cent.
1870	0·00 „
1871	2·65 „
1872	0·00 „

It should be remarked that the rails for the East Bavarian railway were not made until after those of the same period, 1869, had been completed for the State railway, the experience gained in the meantime accounting for the great difference in the percentage of renewals, viz., 0·6 as against 9·0 per cent.; and amongst the causes of failure there were only three cases of rupture, viz., two through the fish-bolt holes, and one at a distance of 3 feet from the rail-end, the remaining defects comprising longitudinal splitting, &c.

If the above results are considered unfavourable, it should be remembered that most of the Bavarian railways are single lines, that a considerable length of the State railways is laid on stone-blocks, and with heavy gradients and sharp curves; also that the traffic on the main lines consists principally of heavy goods trains,

as, for instance, on the single line from Nürnberg to Würzburg, which forms part of the through route between Cologne and Vienna, and where there is a daily traffic of 144 engines and 1,360 wagon-axles. Here, since 1871, have been laid the steel-headed rails, at the most trying places, viz., on gradients of 1 in 100; and up to the present time not a single rail has been renewed. The number and date of laying are:—

1871	556 rails.
1872	1,906 „
1873	1,518 „
Total . . .	3,980 „

The steel-headed rails for the Bavarian State railways weigh 75·3 lbs. per yard, and are rolled in lengths of 19·7 feet, and 20·4 feet.

Where the failures have occurred it has been generally at those parts of the line where blocks are in use. Where sleepers are laid the renewals have been inconsiderable.

D. G.

On Steel-Bronze. By R. Paulus.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiii., p. 140.)

The following data were obtained by the Author direct from General Uchatius.

If bronze, an alloy of copper and tin, containing from 6 per cent. to 8 per cent. of the latter, be cast in the usual way in thin pieces, when cool it will be tolerably homogeneous in all its parts; but, if the castings be made thicker, the parts which come in contact with the mould will be found, on examination, to contain less tin, on account of the rapid decrease of temperature, and, by crystallisation, to have forced the particles richer in tin before them, and produced, in combination with the more gradual process of cooling, a mixture of bronze with free particles of tin entirely wanting in the homogeneity on which the application of this metal to higher purposes principally depends.

Two methods have been adopted to obviate this failing. In the first, the bronze is subjected, while in a molten state, to a strong continuous pressure until cold, when the casting is far superior to ordinary bronze. In the second (first introduced by Lavessière), the molten bronze is run into a thick cast-iron mould, and by this means cooled very rapidly, the casting being similar in quality to that produced by the first method.

To obtain a homogeneous casting it is absolutely necessary that

the cooling take place with equal rapidity on all sides. This is effected by inserting a core of wrought copper, the results of cooling the inside surface by a stream of air, sand, or water being uncertain.

If the polished surfaces of castings of ordinary, and of chilled, bronze be treated with acid, the former will present a mixture full of free particles of tin, varied in structure and unequal in colour; whereas the latter will appear thoroughly homogeneous, equally crystalline and gold-coloured throughout.

The production of a homogeneous mass is the first improvement in bronze, and the first step towards steel-bronze. The second is straining the chilled bronze beyond the limit of its elasticity, because, according to trials the results of which are given below, this metal does not obtain its steel properties in respect of strength, elasticity, and hardness, until it has been strained beyond this point.

Steel-bronze is homogeneous cast bronze which has obtained its utmost strength of resistance, equal to unchilled steel, by being subjected to a tension beyond the limit of its elasticity.

Experiments were made with the following alloys, the last being that used by Lavessière. Two bars were taken from each of the castings, and rolled until they attained the hardness of steel. The first two bars containing 12 per cent. of tin gave way under the rollers, to effect which

	Per cent.		Per cent.
Bronze containing	10	of tin had to be rolled until it was extended	20
" "	8	" " "	30
" "	6	" " "	50
" "	10	of tin with 2 per cent. of zinc had to be rolled until it was extended	10
" "	10	of tin with 1 per cent. of zinc had to be rolled until it was extended	15
" "	8½	of tin with ½ per cent. of zinc had to be rolled until it was extended	20

The qualitative results were:—

Alloy.	Absolute Strength. (In tons per square inch.)	Limit of Elasticity. (In tons per square inch.)	Elastic Extension in 0·00001.	Permanent Extension in per cent. of Length.
Bronze containing 10 per cent. tin	32·128	10·794	174	1·5
" " 8 "	33·017	8·889	140	2·5
" " 6 "	34·668	8·254	128	3·5
" " 10 " with 2 per cent. zinc	19·175	3·810	89	0·5
" " 10 " " 1 " "	26·477	6·349	120	0·7
" " 8½ " " ½ " "	24·128	9·524	157	1·7

These results show that bronzes containing 10 per cent., 8 per cent., and 6 per cent. of tin can generally be used for the new process, and that no advantage is gained by the addition of zinc.

The Author suggests that not only bronze, but wrought iron, steel, and doubtless all ductile metals, if stretched beyond the limit of their elasticity, would really attain a far greater limit. Thus that of elasticity of chilled but unstretched bronze was reached with 2·54 tons per square inch, the elastic tension being 0·004 of its length; whereas, after the rod had been strained until its permanent extension was 0·004 of its length, its limit of elasticity was raised to 10·159 tons per square inch (*i.e.* fourfold), and its elastic extension became 0·00192 of its length.

To form a correct opinion of the results of the trials of the different metals given in the following table, the Author appends the accompanying explanations, that

a. The absolute strength is expressed in terms of the load necessary to overcome the power of cohesion in tons per square inch.

b. The elasticity is the greatest load in tons per square inch that the rod will bear without permanent extension.

c. The tenacity is expressed by the permanent elongation in percentage of the length of the rod at the moment of rupture.

d. The homogeneity of the metal is estimated in proportion to the decrease per cent. in the original section at the point of rupture. If the altered section be just as much less (according to its cubic contents) as the rod has lengthened, the metal may be taken as homogeneous.

e. A comparison between the hardness of the different metals is made by subjecting the flat surface to the blow of a given weight falling from a certain height on to a round-ended chisel, and then measuring the notch, whose greater or lesser length will be proportionate to the softer or harder properties of the metal.

TABLE of the TENSILE STRENGTH of CAST IRON, ORDINARY BRONZE, STEEL-BRONZE, WROUGHT IRON, and STEEL.

Load in tons per square inch.	Cast Iron for Guns. (Styrian.)		Bronze. Cast Bronze.		Bronze. Chilled Cast. Unrolled.		Bronze. Chilled Cast. Rolled Steel B.		Wrought Iron. (Styrian.)		Krupp's Cast Steel for Guns.	
	Extension in 0·0001 of the Length.											
	Elast.	Perm.	Elast.	Perm.	Elast.	Perm.	Elast.	Perm.	Elast.	Perm.	Elast.	Perm.
0·635	2	0	10	0	8	0	2	0	4	0	1	0
1·270	10	0	15	0	15	0	7	0	9	0	3	0
1·905	15	0	25	0	25	0	10	0	11	0	7	0
2·540	22	0	35	0	40	0	22	0	14	0	12	0
3·175	27	0	47	1	53	2	37	0	18	0	16	0
3·810	33	0	56	4	62	4	50	0	22	0	20	0
4·445	38	2	66	7	70	6	60	0	24	0	25	0
5·080	47	4	77	11	79	8	73	0	27	0	30	0
5·714	54	5	88	20	87	10	86	0	31	0	34	0
6·349	61	6	101	32	100	13	96	0	35	0	39	3
6·984	68	8	110	52	108	22	107	0	37	0	44	5
7·619	76	10	120	96	115	47	117	0	40	2	50	7
8·254	84	14	..	..	130	117	128	0	42	3	55	10
8·889	92	19	..	..	150	327	139	0	45	4	60	14
9·524	101	24	..	..	170	380	149	0	48	5	65	20
10·159	110	30	..	..	192	441	159	0	52	6	71	31
10·794	120	35	..	..	..	..	170	0	57	7	76	38
11·429	130	50	..	..	..	..	179	2	62	8	81	48
12·064	142	65	..	..	..	..	193	5	67	8	85	120
12·699	157	81	..	..	..	..	208	8	72	9	90	252
13·334	..	..	..	..	..	..	215	10	77	10	98	360
13·969	..	..	..	..	..	..	222	12	82	12	110	586
14·604	..	..	..	..	..	..	239	14	88	14	..	..
15·239	..	..	..	..	..	..	252	18	93	16	..	..
Absolute strength	15·366		14·350		19·365		32·166		29·842		30·477	
Limit of elasticity	3·810		2·540		2·540		10·794		6·984		5·714	
Elastic extension in per cent. of length	0·033		0·035		0·040		0·170		0·037		0·034	
Permanent do.	0·400		15·000		40·000		2·100		22·000		21·400	
Section at rupture in per cent. of original section	0·960		0·660		0·540		0·960		0·620		0·500	
Hardness according to length of notch	10·200		12·500		12·500		10·200		10·500		10·500	

W. E. T.

On the Physical Properties of the Steels of Commerce, and the Laws of their permanent Deformation. By M. Marché.

(Mémoires de la Société des Ingénieurs Civils, 1876, pp. 187 and 260.)

This Paper contains a collection of documents bearing upon the manufacture and the testing of steel, from which the Author makes some deductions on the physical properties of commercial steels, and on the proper conditions under which tests should be applied. The way in which steel should be dealt with in the operations it has to pass through in the hands of those who use it depends generally upon the "hardness" of the steel, a quality which is only manifested when permanent deflection or deformation takes place. Hence, the Author argues, as the permanent deflection of steel varies with and is characteristic of the quality of the product, the study of the laws is an indispensable aid to the classification of the steels of commerce, and is necessary for those who have to work them.

The data derived from the experiments of Bauschinger, Kirkaldy, Knut Styffe, and Colonel Rosset are referred to. Those of Bauschinger, made on a graduated series of steels having proportions of constituent carbon varying from 0·14 to 0·96 in a hundred manufactured at the Teruitz works, prove that the co-efficient of elasticity is invariable for all proportions of carbon. The experiments of Mr. Smith with Bessemer rails, at Barrow-in-Furness, are quoted to show that the shearing resistance, the tensile resistance, the permanent extension, &c., have a constant relation to the proportion of constituent carbon up to the limit of from 0·8 to 1·2 in a hundred, beyond which the resistances diminish:—say that the maximum resistance corresponds to 1 per cent. of carbon.[1] The annexed table is illustrative of the graduation of the strength of steel. F is the ultimate resistance per square inch of the fractured section, which is a fraction Σ of the original section. The resistance per square inch of the original section, R, is equal to $\Sigma \times F$:—

Relative Tensile Resistance of Steels.

Designation of Steel.		F.	Σ.	$R = \Sigma \times F$.
	Carbon.	Tons.		
Very mild steel,	0·15 per cent. .	76·2	0·250	19·05
Mild steel,	0·30 ,, . .	72·4	0·395	28·60
Ditto	0·50 ,, . .	66·7	0·600	40·00
Hard steel,	0·70 ,, . .	60·3	0·800	48·24
Ditto	0·80 ,, . .	57·1	0·900	51·39
Ditto	1·00 ,, . .	50·8	0·950	48·26
Cast iron,	4 or 5 ,, . .	9·5	0·980	9·31

Between the limits or 0·15 and 0·80 in a hundred of constituent carbon, the resistance is sensibly proportional to the amount of the carbon; and the relation of the resistance R per square

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., pp. 69–75.

inch of original section, to the percentage of carbon γ, for some manufactures of steel is expressed by the following equations:—

	Tons per square Inch.
J. Cockerill.	$R = 44 \cdot 4\gamma + 19 \cdot 05$
Terre Noire.	$R = 47 \cdot 6\gamma + 20 \cdot 32$
Creusot, series A (ordinary steels) . .	$R = 50 \cdot 8\gamma + 13 \cdot 33$
Do. do. B (superior do.) . .	$R = 50 \cdot 8\gamma + 15 \cdot 90$

Passing to a consideration of the problem, to determine the permanent set of a bar of steel under transverse stress, the Author notices the well-known fact, that the limit of elasticity under transverse stress, calculated by the ordinary formula in terms of the moment of inertia of a section, is much greater than the limit of elasticity under direct tensile or direct compressive stress, making a difference, by experiment, of from 25 to 50 per cent. of the tensile limit. This difference, he says, is easily explained by the "fact" that the fibres nearer the neutral axis exert a counteracting force upon the fibres farther from the axis.[1]

M. Marché proceeds to demonstrate that the permanent curvature produced by set, is similar to the elastic curvature which would be produced, on the same portion, by a load equal to R − L, or the difference of the breaking weight and the ultimate elastic weight with a co-efficient of elasticity,—not E the actual elastic co-efficient,—but D the co-efficient of permanent deflection. He finally deduces the formula,

$$f = \frac{N\, l^3}{12\, D\, I} \times \frac{m}{a},$$

showing that the permanent deflection is proportional to the cube of the span l, and to the elastic load N, and inversely proportional to the moment of inertia I, and to the co-efficient of deformation D. m is a complex co-efficient $(1 - a)^2\,(2 + a)$; and a is equal to the ratio, $\frac{N}{P}$, of the elastic load to the greater actual load. The ratio $\frac{N}{P}$ does not descend below $0 \cdot 40$, when rupture takes place, or the deformation ceases to be regular. The co-efficient D varies from (200×10^6), corresponding to the mildest steels, to (600×10^6), corresponding to the hardest steels.

With respect to trials of transverse strength by a falling weight, M. Marché estimates that 50, 60, or, in some cases, even 80 per cent. of the work of the fall is eluded by the piece under trial, and is absorbed by the elasticity of the anvil and the ground, the resistance of the air, &c.

D. K. C.

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[1] This is not the true explanation of the remarkable excess of resistance to elongation under bending stress; for the tension of the nearer fibres is already taken into the reckoning in terms of the moment of inertia of the section and the direct tensile resistance of the material. According to the supposition of the Author, it is also exerted simultaneously upon the farther fibres; but such duplicate action is impossible.—D. K. C.

On Improvements in the Production of Cement Copper at Agordo.

By L. Mazzuoli.

(Annales des Mines, 7th series, vol. ix., p. 190.)

The pyritic mass of Agordo, which occurs as a contact deposit between black schists of palæozoic age and triassic dolomites, consists principally of compact iron pyrites, irregularly intermixed with copper pyrites, blende, and galena; the average proportion of copper, in the portion still unworked, cannot be estimated as exceeding 1½ per cent. The processes followed at the Agordo works, which were described in detail in a memoir by M. Haton in the "Annales des Mines" for 1855, commence with a separation of the minerals raised from the mine into three classes, rich, medium, and poor; those of the first class are fit for the coarse metal furnace without further treatment, while those of the remaining classes are broken into lumps and burnt in heaps, whereby the sulphur is in great part volatilised as sulphurous acid, a small portion being condensed on the surface of the heap, leaving the burnt lumps with kernels or *tazzone* of sulphides of copper yielding from 20 to 50 per cent. of copper, when carefully cleaned from the outer crust of oxidised mineral, which is done by spalling and hand-picking. The kernels are then treated with the rich ores for coarse metal, while the oxidised crusts, consisting mainly of ferric oxide with some sulphates of copper and iron, are subjected to lixiviation to dissolve out the copper salt, which is afterwards recovered by means of scrap cast iron in cementation tanks. Finally, the liquors remaining after the removal of the copper are transferred to wooden tanks, where the copperas is allowed to crystallise out. The coarse metal produced from the rich ores, after calcination in heaps, is converted into block copper and refined. Fusion is effected in blast furnaces, and the refining in the open hearth, after the old German method.

The process, as carried out up to the end of 1874, was affected by two serious drawbacks—an excessive consumption of iron in cementation, from 3·2 to 3·5 times the weight of the precipitate copper obtained, and a bulky deposit of basic ferric salts locally known as *brunini*, which were not only difficult of treatment by the dry way, owing to the presence of arsenic, but which lowered the quality of the cement copper. Owing to the formation of this substance, it was necessary to reject about one-seventh part of the liquors, with a consequent loss of their contents in copperas. In order to arrive at a remedy a series of laboratory experiments was undertaken by M. Zoppi, the director of the works, which have resulted in the improvements to be described. The cause of the large consumption of iron in cementation is obviously due to the presence of ferric sulphate, which acts as an oxidising agent upon the first portions of the

copper separated, reproducing ferrous and cupric sulphates, $Fe_2(SO_4)^3 + Cu = 2(FeSO_4) + CuSO_4$; the copper being alternately precipitated and redissolved until the whole of the ferric sulphate is reduced to the ferrous salt, changes which can only be effected by the expenditure of fresh quantities of iron at each precipitation.

Another reaction which has been proved to take place is the change of ferric sulphate $Fe_2(SO_4)^3$ by metallic iron into ferrous sulphate, $FeSO_4$, and basic ferric sulphate, Fe_2SO_6. This had usually been considered to be a product of atmospheric oxidation upon ferrous sulphate in the cementation vessels; but it is not probable, as the process in question is, at Agordo, carried out in covered tanks at a high temperature, so that the space between the cover and the surface of the liquid is constantly filled with steam, which prevents the access of air during the operation. It is evident, therefore, that the difficulties of the process, waste of iron and formation of *brunini*, were to be entirely attributed to the presence of ferric sulphate in the copper liquors, and could only be overcome by its removal. This has been effected by saturating the water used in lixiviation with sulphurous acid obtained from the poor ores, which decomposes the ferric sulphate, reducing it to ferrous sulphate and free sulphuric acid. The apparatus used is a rectangular covered tank, 16 feet long, 10 feet broad, and 4½ feet deep, of about 4,000 gallons capacity, communicating at one end with two small pyrites burners, and at the other with a chimney 33 feet high. The tank, being filled with liquors from the washing process, is saturated with sulphurous acid, partly by a current from the burners passing over its surface, but principally by being pumped to a height of 16 feet, when it is made to fall over a series of obstructions in the chimney, which, by breaking it up, bring it into intimate contact with the upward current of gas, whence it passes back saturated into the tank. The furnace is of sufficient capacity to reduce the ferric salts in the whole of the liquors which are produced in the lixiviation of forty charges of burnt mineral per month. The reduced liquors are subjected to cementation in tanks containing 78½ cwt. of scrap cast iron, which can be heated by a peat fire. At the commencement of the precipitation, which is conducted at a temperature of 109° Fahr., hydrogen is given off, but diminishes as the iron, becoming covered with copper, is removed from contact with free sulphuric acid in the liquor. On the fourth day the temperature is raised to 118°, and on the fifth to 122°, when 9·8 cwts. of cast iron are added to finish the precipitation. The whole is then left to settle for twenty-four hours, and cooled to 111°, when the clear liquor is run off to the crystallisers. The cement copper is obtained in two conditions; the principal portion, about 70 per cent., which is found in coherent flakes adhering to the fragments of iron, is almost chemically pure, and fit for immediate refining, while the remaining 30 per cent. is in powder, and contains a considerable quantity of arsenic and ferric oxide;

the former is separated by hand and washed in clear water, while the latter is calcined with the coarse metal, to remove a portion of the arsenic, and is afterwards added in the second fusion for blister copper.

The following table contains the results of the new as compared with the old process, 1874 being the last year of the latter:—

	1875.	1874.
Pig iron consumed per unit of copper	2·55	3·27
Loss per cent. of copper contained in the liquors.	7·60	16·40
Peat used in heating the cementation tanks . .	1·93	3·13
Copperas produced per cubic yard of liquor . .	292 lbs.	252 lbs.
Cement in flakes, containing 85·9 per cent. of copper	48·239 tons	—
Average percentage of copper in cement in powder	60·06	54·97
Brunini, average 9·14 per cent. of copper. . . .	—	24·84

The average saving in cost is about £5 7*s.* 6*d.* on each operation, or about £3,200 on the six hundred operations during the year.

H. B.

The Ore Knob Copper Mine and Reduction Works, Ashe County, North Carolina. By EBEN E. OLCOTT, E.M.

(Transactions of the American Institute of Mining Engineers, vol. iii., p. 391.)

The Ore Knob Copper Mine was reopened by its present proprietors in the spring of 1873, and the works have since been energetically pushed forward. It is situated at a distance of 45 miles, over rough mountain roads, from the nearest railway station;—Marion, Virginia, on the line of the Virginia and Tennessee railway.

The deposit worked is a clearly-defined vein, nearly vertical, and traversing, in a direction 61° east of north, the gneissic rocks of pre-silurian age that form this portion of the Appalachian range of mountains. The vein has been proved for a length of over ½ mile, and varies in thickness from 8 to 13 feet. The upper portion of the vein stuff, for a depth of 40 to 68 feet from the outcrop, consists of a more or less porous ferruginous gossan, such as is worked in some localities as an iron ore: below this comes a depth of about 30 feet of so-called "black ore," coloured by copper glance which has been produced by the re-deposition of the copper washed out from the gossan above, and yielding from 18 to 60 per cent. of the metal; and lower again is found the unaltered yellow ore. This last averages, in depth, about 7 per cent. of copper, and can be easily brought up to 12 per cent. by hand-picking. It consists principally of chalcopyrite, nearly of the formula $Cu_2SFe_2S_3$, mixed with magnetite, iron pyrites, quartz, garnet, and other minerals.

So far as the vein has been explored, it presents few of the

irregularities and impoverishments commonly met with in metalliferous deposits; at all points affording paying mineral. About 5,000 tons of ore have already been removed, in opening the mine, and 3,500 tons of this quantity have been subjected to treatment.

The Hunt and Douglas process adopted for extracting the copper is based on the power possessed by a solution of protochloride of iron to dissolve oxide of copper, with the separation of peroxide of iron and the formation of protochloride and dichloride of copper, which latter is retained in solution by keeping the liquor hot, and adding to it so much common salt as to form a strong brine. After drawing off the solution from the exhausted ore, the copper is thrown down from it by metallic iron, and the protochloride of iron, thus reproduced, serves to act on a fresh portion of oxide of copper, and so on indefinitely. The bath having been once made, by adding protosulphate of iron (copperas) to a strong solution of common salt, there is no further consumption of reagents, except the metallic iron used in precipitation, and a sufficient amount of salt to supply unavoidable losses.

The ore at Ore Knob, after being hand-picked, if necessary, is dried in a kiln and crushed by a Blake's breaker, followed by rolls, to such fineness that it passes through a revolving screen of forty meshes to the linear inch.

The crushed ore is roasted in reverberatory furnaces, fired with wood, each of which has three beds, 18 feet by 9 feet, arranged one above the other. The ore is charged, through hoppers, on to the upper bed, in portions of 1 ton at a time, and remains for twelve hours on each bed, before it is pushed through drop-holes on to that below. It remains thus in all thirty-six hours in the furnace, during which time it is rabbled at intervals of three quarters of an hour; and by the time that it is drawn, the amount of sulphur contained in it is reduced to 0·4 per cent., and the copper is distributed as follows:—

As sulphate	3·76	per cent.
" oxide	7·75	"
" sulphide	0·39	"
	11·90	

The ore is now conveyed to the stir-tanks, 8 feet in diameter by 5 feet deep, in which it is treated with the solution of protochloride of iron and common salt. Each tank is charged with 3,000 lbs. of roasted ore, and 1,500 gallons of liquor, marking about 22° Beaumé; the charge being so proportioned that the resulting solution shall not contain more than 30 lbs. of copper in 100 gallons. The mixture is kept heated, by steam, to 160° Fahr., and is stirred for eight hours, and then left for four hours to settle; after which the clear portion of the liquor is drawn off into the precipitating tanks,

and that which is muddy, with flocculent oxide of iron and fine particles of ore, into subsiding tanks. The exhausted ore, in the stir-tanks, is washed and thrown away. The slimes are allowed to accumulate in the subsiding tanks until these are half full, and are then also washed, until they contain only ½ per cent. of copper, when they are run into catch-pits, and drained, to be further utilised as oxides of iron.

The precipitating tanks are 12 feet in diameter by 5 feet deep, and are charged each with about 12,000 lbs. of scrap iron. The temperature is maintained in these also at 160° Fahr. by the injection of steam, and from twelve to eighteen hours' contact in them, with the scrap iron, suffices to precipitate all but a trace of copper from the liquors, which are then drawn off and used again on a fresh portion of roasted ore. The cement copper that is produced contains generally from 75 to 85 per cent. of metallic copper; its impurities being chiefly peroxide of iron and fine particles of gangue. Special lots have, however, been made, containing as much as 96·5 per cent. of copper.

The present works are capable of treating 12 tons of the yellow ore per twenty-four hours; and in the last six months of 1874 an amount of cement equal to more than 400,000 lbs. of fine copper was produced. A refining furnace is now being constructed, in order to make the cement into ingot copper on the works; and great economy is also anticipated from the substitution of spongy iron, made on the spot, for the wrought-iron scrap hitherto used to precipitate the copper.

The Paper is illustrated by general sections of the mine, and of the Hunt and Douglas reduction plant as arranged in actual use.

After the reading of the communication, Dr. T. Sterry Hunt gave some further particulars of the working of the reduction process, and mentioned that it was also being brought into use for the treatment of some of the low-grade copper ores of Pennsylvania.

W. H.

On the Causes of the Obstruction of the Regenerator Passages in Siemens Furnaces. By L. Borbely.

(Zeitschrift des berg- und hüttenmännischen Vereines für Kärnten, vol. viii., p. 26.)

The obstruction of the gas passages in the regenerators of Siemens furnaces have been usually attributed to so-called flue ashes, which, according to the Author, in most works arranged to be worked by gas on this principle fill up all the apertures and passages with a fine red powder, resembling brick-dust, which must be cleaned out at short intervals. That such a deposit cannot, however, be traced to the gas generators, is evident from the difference in composition of the ash of the fuel, which is usually

a coarse grey or reddish powder containing silica and earthy bases, from the dust in question, which is red or violet in colour, crystalline in texture, and contains from 80 to 97 per cent. of ferric oxide.

The heating furnaces at the Saljó Tarján works in Hungary under the Author's management, usually begin to work dull after the regenerator bricks have been in use about three months, and deteriorate progressively, until it is impossible to obtain a welding heat. Upon opening the regenerators of a furnace in this condition, the surfaces of the bricks are found to be closely and thickly covered with the red powder in question, which resembles the rouge or colcothar obtained in making sulphuric acid from copperas. The rate of deposition of this substance may vary considerably under apparently similar conditions of working: thus a furnace on one occasion yielded 225 kilogrammes, and after another turn of the same duration only 120 kilogrammes. No dust is found in the hottest portions of the regenerators, but at these points an actual combination between the bricks and the deposited matter takes place, which, commencing with a superficial glazing, leads progressively to the complete conversion of the bricks into slag.

By analysis the deposit was found to contain 92 per cent. of ferric oxide, 0·7 per cent. of phosphoric acid, traces of hydrochloric acid, copper, and manganese, together with some silica and alumina, which are probably derived from the mortar.

It is evident, therefore, that this is nearly pure ferric oxide, which, having been brought over by the gas in a volatile combination, was on the reversal of the flame decomposed, and deposited ferric oxide. Such a combination is afforded by ferric chloride, which, when exposed to a current of producer gas containing hydrogen, is decomposed with the formation of hydrochloric acid and ferric oxide. In order to test the probability of this view, the whole of the volatile products, including the producer and chimney gases, the tar and liquor deposited in the gas conduit, and the sand forming the hearth bottom, were examined chemically by Dr. Wartha, Professor at the Polytechnic High School at Buda-Pesth, with a view to discover chlorine, with the following results. The tar and tar-water, as well as the waste water, through which a current of producer gas had been drawn for twenty-four hours by an aspirator, were found to be completely free from chlorine in any form, as was also water through which chimney gas had been flowing in the same way. In the latter case, however, a wrought-iron tube about 5 feet long, forming the connection between the chimney and the aspirator, was found to contain a considerable amount of ferric chloride, which was obviously formed by the action of hydrochloric acid contained in the gas upon the metal of the tube, the acid being thus prevented from reaching the water in the aspirator.

The sand employed for the furnace-bed contained chloride of sodium to the extent of 0·04 per cent., equal to 0·024 per cent.

of chlorine. That this quantity of salt would not be sufficient of itself to account for the great amount of deposit formed—amounting in some instances to nearly ½ ton in three months—will be evident on consideration of the following figures.

The sand used daily amounts to about 12 cwt., or in seventy working days in three months to 42 tons. With the above proportion of salt, the total amount of chlorine that could be given off would be 22 lbs., or sufficient to produce about 16 lbs. of deposit. In order, therefore, to produce 10 to 12 cwt. of deposit the sand would require to contain about seventy times more chlorine than it actually does. It is therefore necessary to look for another cause; and this, the Author considers, is to be found in a circulation of hydrochloric acid from the furnace to the regenerators and back, in the alternating currents of gas. Free hydrochloric acid is found, by analysis, in the deposit, which leads to the conclusion that a portion of this gas produced by the action of hydrogen upon ferric chloride escapes volatilisation with the chimney gas and condenses in the cooler parts of the regenerator, where it is absorbed mechanically by the ferruginous deposit. On the reversal of the current, the ammonia contained in the producer gas combines with the acid, forming sal-ammoniac, which is carried back into the heating chamber of the furnace, where, by its decomposition, a fresh quantity of ferric chloride is produced. This, in its turn, is decomposed into ferric oxide and hydrochloric acid in the exhaust regenerators, and so on, a portion of the original chlorine being brought back to act upon the iron in the furnace at every change. Since the reversal of the current takes place ninety-six times in twenty-four hours, it is evident that the cumulative action of a small quantity of chlorine circulating in the above manner will be sufficient to produce a considerable deposit of ferric oxide in eighty or one hundred working days. The nature of the deposit, according to the Author, is similar in all the forges in Austria and Styria, where the Siemens furnace is used, although the actual time that the regenerators can be kept at work without cleaning varies. The longest period appears to be at Komotau, in Bohemia, where furnaces have been kept at work for two years; but in Styria generally the period is from five to seven months. Where coal is used in the gas producers, the dust is often of a dark colour, from the presence of carbon derived from the decomposition of the richer hydrocarbon gases produced in the distillation of the coal. In such cases, however, ferric oxide may generally be found by analysis. As the difficulty is obviously due in the first instance to the presence of salt in the material employed for the bed of the furnace, it might be remedied by washing the sand before use until the whole of the soluble substances present were removed; but this could not be done on a large scale with anything like certainty. It seems, therefore, that a more efficacious plan would be to remove the ammoniacal substances from the producer gas, by passing it through a condensing tower containing coke moistened with weak sulphuric acid, so that it might no longer act the

part of a return carrier of chlorine from the regenerator to the furnace.

The Author points out that the great difficulty in working Siemens puddling furnaces, from the occurrence of the same kind of deposit in an aggravated form, may be due to the custom of throwing water into the furnace to cool it after working off a charge, previously to the introduction of the next, a practice which must result in the introduction of a considerable quantity of salt, present in all natural spring and river waters. As a remedy, it is suggested that the cooling of the bed of the furnace should be effected by an external circulating current of water rather than by direct contact.

H. B.

On the different Systems of Ovens employed in the Manufacture of Window-glass.

By CH. TOCK, C.E., Managing Director of the Mariemont Glass-works, Belgium.

(Revue Universelle des Mines, &c., vol. xxxix., p. 556, pl. 1.)

The cost of fuel represents about one-third of the expenses incurred in the manufacture of window-glass; and yet, strange to say, there is probably no other industry in Belgium in which it is more wastefully consumed, the old-fashioned ovens being almost everywhere retained, notwithstanding the great improvements which have been introduced of late years in other countries, and which, notably by the adoption of gas in lieu of coal, have resulted in an economy of from £400 to £600 per annum per oven in fuel alone, besides other advantages. The object of this Paper is to compare the different systems now in use, and to demonstrate the superiority of gas furnaces, which have as yet been adopted at only two window-glass manufactories in Belgium, viz., the Siemens regenerative furnace at the works of Messrs. Bennert and Bivort, and the Boëtius furnace at Mariemont.

It must be borne in mind that in glass-works, so long as the fusion of the materials is proceeding, an extremely high temperature is necessary, after which it has to be much reduced, in order that the glass may acquire a tough fluid consistency, and be maintained in that state during the time that it is being worked or blown. Consequently, during the earlier period complete combustion of the fuel, but during the subsequent period a moderate heat and a softer or more bituminous flame, are desired by the glass-blower.

The ordinary glass-melting oven is rectangular, and constructed with two raised side-banks, upon which six, eight, or ten melting-pots are placed. Between these banks, and at from 3 feet to 3 feet 6 inches below them, is the fire-grate, extending also throughout the entire length of the oven. Vertical walls and an

arched roof inclose the whole, with openings at either end through which the melting-pots and their contents are introduced, one of which serves also to connect the oven with the chimney. Under the fire-grate is a vast flue, into which the ashes and cinders fall, and through which air is admitted to the fire above.

Such a construction naturally involves a great waste of heat; and the Author shows, by an investigation based on the generally accepted rules, that this waste cannot amount to less than 70 per cent. of the calorific power of the coal, which he estimates at 14,159 British units of heat per lb.; viz., 16 per cent. by excess of air, 15 per cent. by the formation of cinders, 20 per cent. by incomplete combustion of the coals, and 19 per cent. by the draught which carries the burnt gases into the chimney at a temperature of 932° Fahr. (500° C.). This is equivalent to an average loss of from 8*s.* to 10*s.* 6*d.* on each ton of coals used in the works, and to from 1*s.* 8*d.* to 2*s.* on each 100 square feet of glass; and, taking 1,200,000 square feet of glass as the average annual production of each oven, he asserts that by the retention of such antiquated apparatus the Belgian glass-makers may be said to tax themselves annually to the extent of from £1,000 to £1,200 per oven.

These figures show a large margin for improvement; and, with this object, many alterations have been successively tried, but with no practical success until the introduction of gas as fuel.

The Siemens regenerative gas furnace is too well known to require a detailed description, but the Author closely examines its applicability to glass-melting ovens.

In order to estimate the theoretical loss of calorific power in the Siemens furnace, he again takes 14,159 units of heat as the value of 1 lb. of coal, and calculates the loss by condensation of the hydro-carbons and deposition of tar at 996 units, or 7·04 per cent.; the loss by the draught, which he supposes to escape into the chimney, at 986 units, or 7 per cent.; the loss by incomplete combustion of the smoke at 5 per cent.; and the loss of sensible heat, during the progress of the carbonic oxide and of some carbonic acid from the gas-producers to the regenerators, at 4,404 British units, or about 33 per cent., thus arriving at a total loss of 52 per cent. of the calorific power of the coal. This shows a superiority of 18 per cent. over the ordinary coal furnace; but as a higher temperature is obtained in the melting-oven than when coal is used, the practical economy of fuel, as compared with that consumed in the ordinary oven, may be estimated at from 25 to 30 per cent.

A greater rapidity in the operation of fusing the glass, and the production of a more thoroughly fused material, are further advantages with which the Author credits the Siemens furnace; but, on the other hand, he states that it fails during the period of working, or blowing, because the flame from the gas, deprived as it has been during the long passage from the producers to the regenerators, of all its hydro-carbons, is unsuitable in quality for

glass-blowing, besides which it is too intensely bright and dazzling, and affects the eyes of the workmen so much as to prevent the work being well done; it is also constantly varying in intensity, for at each change in the direction of the air and gas currents through the regenerating chambers, the temperature is suddenly increased, and then gradually diminishes again until the next reversal of the current; and, finally, during the time when the glass is being worked, the regenerative chambers are, in the space of a few hours, so much cooled that the combustible gases arrive at the melting-oven in a condition in which they are no longer capable of supplying sufficient heat, and the glass-blowers are consequently stopped in their work.

The Siemens regenerative gas furnace is also too expensive to allow of its being generally adopted in Belgian window-glass works; for, owing to its being composed of so many different parts, an oven intended to hold eight melting-pots costs from £800 to £1,000, and even the conversion of an ordinary coal-burning oven into a gas furnace on this principle, when that is possible, which is not always the case, is estimated to cost from £600 to £800. Few window-glass manufacturers in Belgium could afford such an expense. It is also costly to work, for the regenerators require frequent repairs; and, lastly, it is too complicated for window-glass manufactories, where frequently one person has to superintend four or five ovens, differing in this respect from plate-glass works, which generally support much larger establishments.

The Author proceeds to the question of whether the Siemens furnaces could not be modified so as to adapt them better to the purpose he is examining, and arrives at the conclusion that the regenerative chambers, which are the most complicated and costly part about them, may be advantageously suppressed. He calculates that, by the condensation of the hydro-carbons, 7 per cent., by the escape of the burnt gases, 7 per cent., and by the waste of the sensible heat of the gas during its progress from the producers to the regenerators, 33 per cent., or a total loss of 47 per cent. of the calorific power of the coal, is to be attributed altogether to the use of the regenerators; as against 19 per cent., which ought to be the only corresponding loss from a gas furnace if the arrangements due to the regenerating process were omitted, even though the products of combustion should then escape at the higher temperature of 932° Fahr., as is the case when using coal; and he is of opinion that the advantages due to the higher temperature in the melting-furnace do not compensate for so many causes of waste of heat and for the expensive construction of the regenerators. He considers that the chief value of the Siemens furnace consists in its having established the superiority of gas over coal, and in having proved the advantage of a thorough mixture in proper proportions of the fuel with the supporter of combustion, gas with air, by which means a much higher temperature is attainable in the melting-furnace than would otherwise be possible; but if these advantages could be secured without the

losses of heat above enumerated, then, even though the products of combustion should enter the chimney at a much higher temperature than from the regenerators, results at least equally favourable to those attributed to the Siemens furnace would be arrived at; and this he believes to be what Boëtius, of Hanover, has succeeded in effecting with the furnace which is known by his name.

The chief points of the Boëtius gas furnace are—1, that it insures the complete combustion of the coal; 2, that the air which is supplied for the support of the combustion is heated before it reaches the gas; 3, that the air and gases are intimately mixed before burning; and, 4, that it supplies a flame of good quality suitable for glass-blowing. The heat contained in the products of combustion is generally not used for regeneration. The melting-oven is constructed close above two gas-producers, one at each end of it and separated by a block of masonry lined with firebrick. Inclined fire-grates, resembling those in the Siemens gas-producer, admit air for the partial combustion of the coal, which is charged and stoked from above, and gradually slides down the sides of the producer, which are more steeply inclined than the grates. The air to support the combustion of the gas is admitted to the upper part of the producers, through a number of small horizontal flues built into the masonry immediately below the bed of the furnace, by which it is heated before it mixes with the gas. The volume of air so admitted can be regulated at will, by plugs or registers on the outside of the furnace. The products of combustion are drawn off from the floor of the furnace through chimneys which are built into the side masonry. The gas from the producers enters the melting-oven immediately above them, through two openings about equidistant from each other and from the extremities of the oven. The small flues which admit air all converge towards these two points. The producers are arched over, and the floor of the furnace rests upon this arch and upon the central block of masonry. Under each fire-grate is an ash-pit communicating with a large flue through which the ashes are conveyed away. The temperature in the furnace can be graduated by the admission of air through the air-flues, and by the generation of gas in the producer, which can be controlled by the stoker.

This system of furnace carries all the sensible heat, generated when the gases are produced, at once into the melting-oven, the hydro-carbons are not wasted, the coal is completely consumed without occasioning, so to speak, any cinders, the gases are intimately mixed with the requisite proportion of hot air to secure their entire combustion, no excess of air is admitted to the furnace, and the causes of loss of heat are reduced to one only, namely, to the escape of the products of combustion at a higher temperature than is the case when regenerators are used. If this temperature were 962° Fahr., as was supposed when estimating the loss in the ordinary coal-consuming ovens, it would represent

only 19 per cent. of the calorific power of the fuel, but if it were double that, or 1,832° Fahr. (1,000° C.), the loss would still only amount to 88 per cent.; and the Author will even suppose that there is a further loss of 10 per cent. due to all other causes. This only makes a total of 48 per cent., which establishes an economy of fuel of from 25 to 30 per cent. as compared with the ordinary coal-consuming ovens; and in practice this is more often below than above the actual results obtained by the use of the Boëtius furnace.

The furnace is extremely simple and easily worked; the frequent repairs required by the brick piles in the Siemens regenerators are avoided, and the gas-producers will last through two seasons without being touched. The melting-oven can be repaired without putting out the fires; by slipping two tiles over the gas inlet holes and spreading a layer of sand over the bed of the oven, the workmen can enter it and do whatever may be needful, even to taking down and renewing the arched roof.

With regard to its suitability during the glass-blowing process, some alterations have been found necessary. In Germany, where this furnace was originated, it is the practice to work up the glass in retorts abutting upon, but not forming part of, the melting-oven, and there it is usual to attach one such retort, at which two blowers can work, to each of the four corners of the Boëtius furnace. In Belgium, however, there are strong prejudices against such a system; and the Author was the first to adopt an alteration suggested by M. Boëtius, which allows of the Belgian practice being retained, of working the glass in the oven itself, and which has been found successful in maintaining an equable and moderate temperature as well as a good quality of bituminous gas during the period when the blowers are at work. This consists in having an additional auxiliary gas-producer at a few yards' distance to supply gas through the central block of masonry under the melting-oven, to which it is conducted by a horizontal flue about 2 feet square, and compensates for the escape of heat through the openings where the blowers work, thus preventing the too rapid cooling referred to as one of the objections to the Siemens furnace.

The Boëtius furnace, as compared with the latter, is also cheaper to construct and more easily and economically worked and kept in repair; besides which it has the immense superiority of supplying a flame far more suitable in quality for glass-blowing, and it is at least as economical of fuel as the Siemens furnace, if not still more so.

The ordinary window-glass melting-ovens now in use might be altered to Boëtius furnaces at an expense of about £320, which would be saved in less than a year's work, because from £480 to £600 per annum would be economised in fuel alone; and where the escaping products of combustion can be utilised for heating steam boilers, or for other purposes, as at the glass-works of

Val-St.-Lambert, the saving in fuel, as compared with the ordinary furnaces, would be increased from 30 per cent. to 40 or 45 per cent.

O. C. D. R.

Steam Boilers and Chimneys. By ROBERT BRIGGS.

(Journal of the Franklin Institute, April 1876, pp. 246–255.)

This article, written by one of the Committee on the Horse-Power of Boilers, appears as an interim memorandum on the relations of grate-area to the horse-power, and to the dimensions of chimneys of stationary boilers.

The Author assumes, on general evidence, that one-fourth of the heat generated in the fireplace of an under-fired boiler is immediately absorbed by radiation into the boiler above the fire, and that therefore the disposal of only three-fourths of the total heat is dependent upon the extent of heating surface beyond the fire. On this assumption, he estimates and compares the performances of two flat-ended plain cylindrical boilers, under-fired, 4 feet in diameter, and 42 feet and 22 feet in length, respectively, and set in the same manner. The fire-grate for each boiler is 4 feet square, giving 16 square feet of area, and the net lengths exposed as heating surface are respectively 40 feet and 20 feet. Each boiler has a chimney 70 feet high, with a sectional area of 1⅓ square foot. With these proportions, 12 lbs. of egg, or steamboat, anthracite, exclusive of ash and cinder, per square foot of grate per hour, may be consumed with ease; and with the 42-feet boiler, a fair specimen of approved proportions, the temperature in the chimney is 450° Fahr. when 60 lbs. steam, at 305° Fahr., is generated.

To trace the disposal of the heat, the total heat of combustion of 1 lb. of coal is taken at 15,000 units, less 10 per cent. for imperfection of combustion, or 13,500 units. Allowing 24 lbs. of air at 60°, the gases, at 450°, carry away 2,300 units, leaving 11,200 units, capable of evaporating 11·6 lbs. of water. Assuming that a fourth of the heat is absorbed directly over the fire, the temperature over the bridge would be 1,765°, and the progressive reduction of temperature in the flue is thus indicated:—

At the bridge,	1,765°	10 feet off,	1,073°	20 feet off.	711°	30 feet off.	519°
2 feet off .	1,589	12 " "	980	22 " " .	662	32 " " .	494
4 " " .	1,425	14 " "	900	24 " " .	619	34 " " .	470
6 " " .	1,300	16 " "	828	26 " " .	581	At chimney,	450
8 " " .	1,179	18 " "	766	28 " " .	548		

By this scale, it appears that for the 22-feet boiler, having only 16 feet of run in the flue, the temperature at the chimney would

be 828°, or 378° more than for the 42-feet boiler, equivalent to a loss of 2,255 units, or 20 per cent. of the total heat available for making steam.

The Author gives an approximate rule for the minimum sectional area of chimney, square or round, which should be directly as the grate-area, and inversely as the square root of the height of the chimney; and he provides a constant of ½ square foot of section as an allowance for the resistance in the flues and the chimney to the passage of the gases. The formula is

$$\text{Sectional area of chimney in square feet} = \frac{\text{grate area} \times 0 \cdot 7}{\sqrt{\text{height}}} + 0 \cdot 5.$$

Again, he deducts 2 square feet from the area of grate for dead corners, &c., as inoperative, and gives a table of the "Proper Sectional Areas of Chimneys" of from 25 to 140 feet in height for grate-areas of from 6 to 40 feet. He assumes a constant combustion at the rate of 12 lbs. of coal per square foot of grate per hour, less 2 square feet, evaporating 1 cubic foot of water (62½ lbs.) from and at 212° per hour for 0·55 square foot of grate, which is taken as for 1 nominal HP.

D. K. C.

On a new Man-Engine at Clausthal.

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, vol. xxiv., p. 169.)

The deep shafts of the Upper Harz mines, which have now reached to about 370 fathoms from the surface, have hitherto been provided with man-engines worked by water-wheels. During the past year, owing to shortness of water, it was often necessary to stop working them, so that the miners were obliged to return to the old practice of travelling in and out of the mine by ladders, to the great detriment of their health and working power. In order to obviate this inconvenience a man-engine, driven by steam, has recently been erected in the Queen Mary shaft in connection with the new deep working, which extends to a vertical depth of 356 fathoms. The engine is of the double-rod or original Harz type, but of wrought iron instead of wood. Each rod is made up of two parallel lines of wrought-iron bars, with wooden platforms fixed between them. The latter are sufficiently large to allow the men to cross over when meeting at the change of stroke. The length of stroke is 12½ feet. Power is furnished by a 50-HP. Corliss engine making forty-five revolutions per minute, which are reduced by spur gearing to 3¾ strokes per minute on the rods. At this speed three hundred men can be brought up from the bottom workings (356 fathoms) in one hour and forty minutes. The engine is kept at work twelve hours daily, during which time six hundred men are taken in and out of the mine with a consumption of 20 cwt. of coal.

H. B.

Pneumatic Malting. Report by J. A. BARRAL.

(Bulletin de la Société d'Encouragement, August 1876, p. 413, pl. 47.)

The process of malt-making, as carried on in most countries with the ordinary construction of malthouse and kiln, is confined in its working to from five to about eight months of the year.

At the brewery at Maxéville, near Nancy, the production of which, in 1875, was about 1,321,300 gallons of Vienna beer, M. Galland, the manager, has introduced several improvements upon the old process of malting, and that considered most important is called by him "pneumatic malting," as artificially-produced currents of air are necessary to the new process. Malting may thus be carried on throughout the year, and under circumstances nearly always identical, the manufacture being converted from an intermittent to a continuous one, and the quality of the produce being rendered nearly uniform. The ordinary process of malting necessitates large germinating floors, as the thickness of the beds of steeped barley must not exceed 8 inches, while to avoid unequal heating, just previous to and during the process of sweating, the grain must be frequently turned and shifted. Owing to the necessity of conducting the process in comparative obscurity, the malting floors are placed low down in the building, and this, coupled with the need of preventing a free circulation of air, which might dry the surface, tends to produce a mouldy flavour. The principle of the invention consists in forcing air, always at the same temperature and at the same degree of humidity, over the beds of grain with a velocity sufficient to carry off the excess of evolved carbonic acid. As beds of grain of from about 12 to 18 inches in thickness may be effectually operated upon, the area of the floors may be correspondingly decreased. The lower part of the building, of masonry and cement, is divided into closed spaces for germinating; these are disposed on each side of the centre line of the house between the central and side galleries, and are in communication with the central gallery by which the fresh air is distributed, and with the outer galleries by which the polluted air is carried off.

Two magazines, filled with coke or similar material, are placed at one end of the building, and a fine spray of well water at about 54° Fahr. is kept constantly playing upon the coke. At the other end of the building are placed fans, which draw the fresh air through the coke magazines, where it becomes cooled and moistened, and from thence through the central gallery and germinating chambers, the polluted air being forced on by the fans through the outer galleries and back to the coke magazines, where it gives up the carbonic acid it has absorbed, and becomes again cooled by contact with the water spray and wet coke. M. Galland employs 8·4 cubic feet of air per superficial foot of germinating grain per minute, 95 per cent. of this being air re-used, and 5 per cent.

being new air. The thickness of the beds may be as much as 19·5 inches, and beds from 12 inches to that thickness have been tried with equal success. The power required for keeping up the currents of air is from 10 to 12 HP. for a malthouse doing sixty sacks per day. The advantages are said to be—reduction of four-fifths the usual area of the floors, reduction by one-half of the labour, absolute regularity of germination throughout the year, and absence of mutilation of the grain during malting operations. At present the results as to cost have been satisfactory, M. Galland stating it to be for the old and new processes as 4 to 2·12 respectively. The Plate illustrating the report gives horizontal, longitudinal, and transverse sections of the building and of all the arrangements.

W. W. B.

Manufacture of Briquettes at the Graissessac Coal Mines.

By M. Savy.

(Bulletin de la Société des Ingénieurs Civils, 1876, p. 176.)

Graissessac coal, in the department of the Hérault, is in general very friable; the proportion of small coal amounts to nearly 70 per cent. of the total quantity extracted. In the formation of briquettes, a proportion of powdered coke, refuse from the Appolt furnaces, is mixed with the slack; and pitch, reduced to powder by Carr's disintegrator, is the only cement employed. Three of David's machines are at work, one of Mazeline's, and one of Révollier's. Their combined production averages 500 tons of briquettes per day of twenty-four hours.

David's machine consists of a pair of wheels which revolve in contrary directions, like the two rolls of a rolling mill. One cylinder (*mouleuse*) carries the moulds, and the other (*comprimeuse*) gears, in effect, into the first, and closes with the utmost exactness the orifices of the moulds filled with the paste of small coal. Before being charged into the moulds, the elements are thoroughly mixed in a sort of pug-mill where they are heated by two jets of steam, which at the same time melts the pitch. This machine works well enough when kept in good repair; but the friction is considerable, the wear is rapid, and the cost for repair is high.

In Mazeline's machine, compression is produced by the play of a steam-piston connected to a lever of the second order, which raises each plunger into its respective mould. The plate which carries the moulds revolves on a vertical axis. The materials are mixed and supplied to the machine by hand; 65 tons of briquettes, each of 10 lbs. weight, are produced in ten working hours. This machine has been at work for eight or nine months, night and day, without requiring heavy repairs, and it turns out briquettes of good quality in considerable quantity.

The hydraulic machine of Révollier works with an alternating rectilinear motion, and carries only two mould frames. The steam-cylinder is 22 inches in diameter, with a 40-inch stroke; and the velocity of the piston is 390 feet per minute. The effective mean pressure on the piston is 2½ atmospheres. By means of two systems of pumps, hydraulic pressures of 48 atmospheres and 600 atmospheres are maintained; the former pressure is applied in the first stages of moulding, and for the discharge of the finished bricks, while the latter pressure is employed for the completion of the briquette. The produce of this machine is comparatively insignificant, and out of proportion to the quantity of machinery set in motion.

The annual quantity produced, and the cost of manufacture, of briquettes by the three machines is:—

	Tons.		Per ton. s. d.
Two small machines. . . .	82,164	at	13 10¼
Hydraulic machine	12,185	„	13 8¾
Total annually . .	94,349		

The density, or specific gravity, of the briquettes, is 1·15 by David's machine, 1·27 by Mazeline's, and 1·38 by the hydraulic machine. The cohesion increases with the density.

In the course of the discussion on this Paper, M. Arson stated that the Gas Company of Paris had succeeded in manufacturing briquettes from coke-dust, by the intermixture of 10 per cent. of pitch, and the employment of enormous pressure. Carr's disintegrator was of service in finely dividing and in mixing the materials. The first trials were made without the addition of moisture, and without success. Steam was introduced, and the briquettes were much better. It was inferred that steam was useful not only by heating the pitch and rendering it more binding, but also by moistening the mixture. M. Gillot ascribed this to the fact that the water is decomposed, and its hydrogen combines with carbon, forming a hydro-carbon, or tar, which assists in the agglutination of the mass.

D. K. C.

Manufacture of Briquettes of Lignite by dry Compression.

By A. Wilcke.

(Revue Universelle des Mines, vol. xxxix., p. 382.)

The most considerable improvement made of late years in the lignite industry has been the utilisation of the slack. By special construction of furnaces the lignite slack had been successfully dealt with in manufacture, but it could not be used in its

unprepared state for domestic purposes. To enable it to be thus employed, it had been agglomerated, by the aid of pitch, into briquettes. These, however, even when as a further improvement subjected to a heavy pressure, were so friable that the deterioration in carriage confined their use to the vicinity of the manufacture. Recently these objections have been overcome by the aid of the following processes.

The lignite slack, having been passed through a riddle, is desiccated, and is then subjected to pressure in a heated press, which, it is stated, produces briquettes not only competent to bear transport without injury, but also of great density, and of a calorific effect exceeding, for equal volumes, even that of coal itself.

The apparatus employed subsequent to the riddling is of the following kind:—

The drying stove may be heated by steam, which, so far as the risk of igniting the slack is concerned, is the preferential plan; but, owing to the slowness of the process and the cost of the apparatus, it is discarded in favour of desiccation by direct contact with the hot products of combustion from a furnace. These hot products may be the waste heat of a steam-engine furnace, but preferentially they are derived from a special fire. The stoves are circular brick or masonry chambers, from 10 to 13 feet in diameter and about twice as high. In these chambers are placed horizontal trays, from 12 to 20 inches apart, on which the slack is spread, and having in each alternate tray openings near the circumference, while the intermediate trays have openings near their centres.

In the middle of the stove there is a vertical shaft making from two to three revolutions a minute. In some constructions this shaft supports the trays, which revolve with it and carry round the lignite slack under the action of scrapers attached to fixed bars, and so adjusted as, in the alternate trays, to cause the slack to travel from the centre to the circumference and then to fall through the openings on to the intermediate trays, the scrapers over these being adjusted so as to make the slack travel from their circumferences to their central discharging orifices. In this way the riddled slack, which had been fed in by openings in the top, is made to descend through the stove from tray to tray, being thoroughly stirred during the process. In the other construction the trays are fixed, while the revolving shaft carries radial arms to which the scrapers are attached. This plan, however, is not considered to be so good as that first described; because, notwithstanding every care is taken, by making the heated gases enter by numerous openings at one side of the stove and issue by several outlets at the other, it is not found possible to obtain uniformity of temperature throughout, a difficulty which is successfully met by causing the trays to revolve.

The Author recommends a separate furnace for each stove, and gives directions as to its construction and mode of firing, so as to prevent the carrying into the stove of sparks, which might set fire

to the lignite. He points out that the heated gases should contain as little moisture as possible, and that therefore the fire should not be made with undried lignite. He states that the temperature in the stove should be from 480° to 500° Fahr., and should never exceed 570° Fahr., as otherwise hydro-carbon gases might be evolved from the lignite and might lead to an explosion.

The bottom of the stove is funnel-shaped, so as to lead the dry lignite to double outlets, each provided with pairs of slides placed at a considerable distance apart, with an apparatus like a large hollow plug-cock,[1] so as to admit of the dried lignite being cooled before withdrawal, and also of its being withdrawn without allowing the atmosphere to enter the stove. It is desirable that the vertical shaft should be driven by a special steam-engine, in order that the rate of travel of the lignite slack may be varied according to its size, the amount of moisture it contains, and the temperature prevailing in the stove. Under good management, as much as 20 per cent. of moisture is expelled from the slack in its descent from the top tray to the outlet.

The dried slack, by means of an elevator and a screw, is fed into the hopper of the press. This consists of a steam-jacketed tube furnished with steel moulds, of the section of the briquettes; within these moulds a plunger reciprocrates, driven by a crank with connecting rod from an engine shaft, provided with a fly-wheel on each side of the press crank. At the commencement of the operation the outlet of the moulds is closed by a stopper, but after a few strokes, the friction of the undischarged briquettes is sufficient to form a proper abutment for the pressure.[2] The resulting briquettes have a smooth surface, are very hard, and have a gravity of 72 lbs. per cubic foot; while the original material, which contained the 20 per cent. of moisture driven off by the stoves, had a gravity of only 46 lbs. per foot.

It is stated, that a stove having nine trays produced 20 tons of dried lignite per day. To make this quantity, 715 bushels of raw lignite were required; while to heat the stove, from 110 to 160 bushels of briquettes or lignite were consumed.

Up to the present time the cost of briquettes, including materials and labour, has been 11·25 francs, or 9*s.* per ton; but it is hoped that, with a better disposition of machinery, the cost may be reduced to 7·35 francs, or 6*s.* per ton.

B.

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[1] Both these arrangements are commonly employed for the withdrawal of the produce of the running retorts used in sugar factories for revivifying the animal charcoal.—B.

[2] See the specification of Mr. Henry Bessemer's patent of the 17th of April, 1849, No. 12,578, for the expression of juice from the sugar-cane. See Inst. Mechanical Engineers, Proceedings, 1875, p. 147, Mr. Charles Hodgson's Paper on Compressed Peat Fuel.

On the Working of highly inclined Coal Seams of great thickness at Dombrowa in Poland. By M. Joukowsky.

(Bulletin de la Société de l'Industrie Minérale, 2nd series, vol. v., p. 353.)

The coal seams of Dombrowa, forming an extension of those of the Upper Silesian basin at Zabrze, Myslowitz, &c., are of great thickness, and dip at a considerable angle. The coal is dry, unfit for coking purposes, and very inflammable; conditions which render the working difficult, as special methods are required in order to get as much large coal as possible, the slack being comparatively valueless, and liable to give rise to spontaneous combustion. The calorific power, however, being high, the ash small (not exceeding 4 per cent.), and sulphur almost completely absent, the coal is in considerable demand for metallurgical works, locomotives, and domestic consumption. The average price during the last four years has been about 10*s.* per ton for large coal, but only about 1*s.* for rough slack.

The method to be described has been adopted at Nowo Labenzky and Cieshkowsky, where the seam is from 52 to 59 feet thick, and varies in inclination from 15° to 40°. At these places it was originally worked in open-cast, but the rapid increase in the amount of cover to be stripped, owing to the sharp dip, has rendered the continuance of this plan impossible.

In laying out the underground workings, the French method of taking the coal in horizontal slices and packing the openings with earth from the surface (*remblais*) was found to be objectionable, both on account of the cost of timber and packing material, and the crushing of the coal by the irregular shrinking of the filling material, which produced such a large proportion of slack that the mine could not be worked at a profit. It was decided, therefore, to adopt a modified system, in which the coal is taken in slices from above downwards, but without packing, and this has been carried out in the following manner:—

The seam, which dips towards the pit, is laid open by a pair of cross-cut levels about 33 feet apart vertically; when these levels reach the coal they are continued right and left on its course, keeping close to the line of intersection with the roof, and preserving their relative positions. The upper one of these is used as a main drawing road, while the other serves as a drainage and return air-way. At intervals, varying from 260 to 360 feet, rise headings are driven in pairs parallel to each other, about 23 or 26 feet apart, but of unequal section, the larger one being intended for conversion into self-acting inclined planes, while the smaller, designed primarily for ventilating purposes, is used by the miners as safer for travelling than the main inclines. In driving these headings a thickness of about 3 feet of coal is left on the roof side, below the actual roof, which is a black, carbonaceous shale, often very combustible, and even liable to spontaneous ignition.

From the top of the rise heading a gallery is driven right and left on the roof side, parallel to those below, and the coal is divided for working by headings, which are driven across to the floor of the seam at regular intervals, leaving pillars 40 to 43 feet thick between them. These headings are from 8 to 10 feet in height, the coal being worked in stages about 13 feet thick, so that a thickness of solid coal of at least 3 feet is left as a temporary roof to support the waste of the upper stage previously worked out. The stripping of the pillars is commenced in the centre of the panel formed between any two of the inclined planes, after removing the roof coal, by cutting back the pillars in a direction parallel to the cross headings for a breadth and length of 20 feet and a height of 13 feet, timber props being used to protect the working faces. When the whole of the coal is removed, a layer of small wood and props is placed on the floor, forming a kind of cushion, which distributes the pressure of the fallen rock and waste over the surface of the next lower stage in such a manner that the roof, although consisting merely of broken stuff, is sufficiently coherent to be kept up by the use of timber props. When the pillar has been entirely removed, the roof is allowed to come down by withdrawing the props, wherever it is possible to do so, but those that are too tightly held are shattered by small charges of dynamite. Usually three stages may be worked at a time; while the pillars are being removed in the uppermost, the headings are driven in the one below, and the longitudinal galleries are being driven in the third.

The coal being always supported upon a firm bed is not liable to crushing, and thus one of the principal causes of spontaneous ignition is avoided. In the event of fire, however, there would be but little difficulty in mastering it, as the pillars are only 40 feet broad, and may be approached from three sides. In order, however, to obtain the full benefit of the method, it is necessary to pack the excavations formed by the first four or five stages at the top, so as to have a protecting cushion for the workings against falls of rock from the sides of the old excavations.

The proportion of round coal obtained by this method is 65 per cent. of the total quantity raised. The total cost of getting is 6*s*. 4*d*. per ton, while the average selling price, taking round and slack together, in the proportion of 6½ tons of the former to 3½ tons of the latter, is 7*s*. 4*d*., leaving a profit of 1*s*. per ton. If the method of packing had been employed there would have been a loss of about the same or rather more from the larger proportion of slack produced.

H. B.

On the Composition of the Return Air Currents in the Saarbrücken Collieries. By A. SCHONDORFF.

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, vol. xxiv., p. 73.)

The object of the investigation described in this memoir was to obtain if possible a test of the efficiency of the ventilation in collieries, by determining the amount of alteration experienced in the constituents of the air in its passage through the workings. In previous investigations of the composition of the gases of coal mines, attention has been directed principally to the exhalations of the coal itself, and the results, though of great scientific interest, were necessarily of small value to the miner, as affording no measure of the probable deterioration of the air due to any one working face, and still less the effect of the total exposed surface of coal, which can only be determined by the analysis of samples of the air taken in the main return air courses after passing through the mine. This has been done by the Author in nineteen cases, with the details of the analyses in full. In each instance anemometer observations were made, and the volume of air passing the place of observation was determined at the time when the sample was collected. The account of each experiment also notices the length of air course, distinguishing parts that are in cross-cuts or stone drifts from roads or working places in the coal, and the number of men and horses working in the area ventilated by the current. The analyses were carried out according to Bunsen's gasometric methods, with modifications in details, the constituents determined being carbonic acid, marsh gas, oxygen, and nitrogen, which were computed in volumes per cent. The results of the analyses being compared with air of normal composition—taken as containing, oxygen, 20·95; nitrogen, 79·01; and carbonic acid, 0·04 per cent.—gave the percentage deterioration, *i.e.*, the diminution of oxygen and the increase of carbonic acid and marsh gas, which were afterwards computed by the anemometer observations upon the volume of air passing through the mine per hour, indicating what is called by the Author the hourly total deterioration, or the number of unit volumes (in this case cubic mètres) of oxygen lost, and carbonic acid and marsh gas absorbed, by the total volume of air. The total deterioration is produced by two sets of causes: the first, including the respiration of men and horses, and the combustion of oil in the lamps used in lighting the works, and of gunpowder in blasting, being dependent upon the working strength of the pit, is capable of determination from known constants; while the second and more important set, due to the chemical changes in the mine, cannot be determined from individual factors, but is represented by the difference between the total deterioration and that calculated as due to the men and horses at work. This quantity being divided by the distance travelled by the air through the workings, from the downcast to the

point of observation, affords a measure of the so-called chemical temperament of the mine, *i.e.*, the amount of deterioration per standard unit of length, in this case expressed in 1,000 mètres, which may be used as a means of comparison between mines under dissimilar conditions of extent and working strength. The following example gives the nature of the Author's method of computation :—

EXPERIMENT No. 17.—HEINITZ MINE, 20th Sept., 1875. MAIN RETURN CURRENT.

Length of air-way 73,000 mètres, including 7,800 mètres cross-cut roads, and 65,200 mètres roads and workings in coal.
Working strength, 727 men and 10 horses.
A. Volume of air (reduced from anemometer observation) 47,655 cubic mètres per hour.
B. Composition of air (result of analyses) expressed in volumes :—

Nitrogen 79·461	Oxygen 19·403	Carbonic acid 0·699	Marsh gas 0·247
Deterioration	−1·719	+0·659	+0·247

C. Results computed in cubic mètres :—

	Loss.	Gain.	
Hourly total deterioration . . .	Oxygen 819·20	Carbonic acid 312·05	Marsh gas 117·71
Deduct for 727 men and 10 horses .	37·71	28·89	..
Total chemical action of mine . .	781·49	283·16	117·71
Which divided by 73 gives the deterioration per 1,000 mètres in the chemical temperament . . .	10·71	3·88	1·61

The alteration produced by the powder used, amounting to about 8·8 kilogrammes (19·4 lbs.) per hour, is so small that it may be neglected.

The average total deterioration, as deduced from nineteen experiments, was: Oxygen, 268·79 lost; carbonic acid, 117·75, and marsh gas, 89·12 increase, of which only oxygen 15·67 lost and carbonic acid 12·09 increase were due to the men and horses, or about $\frac{1}{17}$ of the total loss of oxygen, and $\frac{1}{9}$ of the increase in carbonic acid.

The chief causes of the deterioration of the air by chemical changes in the mine workings, are, the slow alteration and decomposition of the coal, the decay of wood used in timbering, and the oxidation of iron pyrites. The relative importance of these different factors, or rather of the first two, cannot be even approximately determined; but the Author points out, from reasons that are developed in detail (p. 109), that the absorption of oxygen consequent upon the oxidation of iron pyrites in the coal, may be determined from the amount of sulphates found in the water pumped from the mine. Applying this method to the Heinitz

mine, he finds the hourly change due to this cause to be 25·05 cubic mètres of oxygen lost, and 15·46 cubic mètres of carbonic acid increase; or nearly as much as that due to the men and horses when the mine is in full work.

In endeavouring to apply the results obtained as a measure of the necessary volume of fresh air for a given extent of workings, the Author first points out that no determination of any value can be founded upon the mere requirements of the working force for respiration and lighting. The rule laid down by the French Government in 1872, which requires the nominal volume of air passing through the workings in cubic mètres per second to be from $\frac{1}{10}$ to $\frac{1}{20}$ of that of the number of tons of coal raised in the twenty-four hours, is shown, by comparison with the conditions observed in the Saarbrücken mines, to give quantities which, in most instances, are far in excess of the real requirements of the case. From the results of his own experiments, the observed condition of the mines in regard to the health of the miners, and the comparative absence of gas in dangerous quantity in the return air, the Author deduces the following limits of alteration as characteristic of well-arranged ventilation:—

	Per cent.
Oxygen, minimum diminution	1·5
Carbonic acid, maximum increase	0·5
Marsh gas „ „	0·6

the proportion of the latter gas being about $\frac{1}{10}$ of the minimum quantity required to make the air explosive.

Upon this basis the necessary volume of air may be computed from the following formulæ:—

$$M_1 = \frac{1 \cdot 11}{1000}(T_1 L + 50 \cdot 5 B + 100 P),$$

$$M_2 = \frac{3 \cdot 33}{1000}(T_2 L + 38 \cdot 5 B + 90 P),$$

$$M_3 = \frac{2 \cdot 78}{1000}(T_3 L);$$

where L = length of air course.
T_1 = loss of oxygen in chemical temperament.
T_2 = increase of carbonic acid „
T_3 = „ marsh gas „
B = number of men at work.
P = „ horses „

Of the three values M_1, M_2, M_3, found by the above formulas, which represent the requisite volumes of air, deduced from the proportions of oxygen, carbonic acid, and marsh gas respectively, the largest must of course be taken. As the proportional deterioration decreases with the depth of the workings, it will also be necessary to increase the quantities of the chemical temperament.

When it is intended to provide for the ventilation of deeper measures by a new upcast, the value of L must be sufficiently large to allow for future extension of workings.

In conclusion the Author points out the necessarily imperfect character of the investigation, which he has published partly as a first contribution upon a subject where information is almost entirely wanting, but more particularly in the hope that it may be pursued at greater length by other observers.

An Appendix to the memoir (pp. 126–133) contains a tabular statement of the appliances for ventilation in use in the Saarbrücken mines at the end of the year 1875. They include—

		Cubic mètres per minute.
14	Guibal ventilators with a total average duty of .	12,487
6	Zimmermann ventilators „ .	1,228
20	furnace „ „ .	10,824
40	Together	24,539

The Guibal fans have an average diameter of 23 feet and 6·5 feet breadth of face. Those of Zimmermann, of 5·5 feet diameter and 1·6 foot breadth. The furnaces range from 8 square feet to 97 square feet of grate surface. The longest air course in connection with a single ventilating fan is 18,416 yards, the amount of air passing being from 31,770 to 42,360 cubic feet per minute. The longest line of furnace ventilation is in the Heinitz mine, where from 25,000 to 30,460 cubic feet of air per minute are drawn through about 48 miles of workings, occupied by 1,560 men, by a furnace of 33·6 square feet of grate surface, consuming 83 cwt. of coal per day. This excessive length of air course is, however, to be diminished on the completion of a new upcast shaft now in course of sinking, when the workings will be divided into two districts for ventilation purposes.

H. B.

On an Experiment in Shaft-sinking by the Diamond Borer.

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, xxiv., p. 169.)

At the Von der Heydt colliery near Saarbrücken, an experimental trial has been made of the American method of shaft-sinking, by boring a series of deep holes, which are then filled with sand, with the exception of a short length at the top, which is charged with dynamite and fired. In this way only the ground surrounding the neck of the hole is broken, and when removed a fresh length is cleared out and loaded, displacing a second depth of ground similar to the first, and so on. The machine employed was a diamond boring engine brought from New York, of a compact construction. The rotatory motion of the horizontal axis driving the boring spindle was produced by a block or piston

rotating upon a crank working within the body of the main steam piston, which is rectangular and moves vertically. The back of the driving axle carries a fly-wheel and winding drum for raising and lowering the rods, the whole being fixed upon a cast-iron bed about 3 feet long. The boring spindle is of the ordinary tubular construction adopted in these machines, and has a vertical travel of about 2 mètres. At the lower end it is connected by a cross-head with the pistons of two vertical hydraulic compressor-cylinders, which can be used to increase or diminish the load upon the rods to the extent of 3 atmospheres, by admitting water from a cistern under a head of 30 mètres, above or below the pistons. The boring rods are drawn gas-pipes of 1-inch diameter, carrying a diamond crown borer with a split ring in a chamber near the bottom, forming a spring catch for bringing up cores.

In setting the machine to work it is of primary importance that the line of the rod should be vertical. For this purpose the line must be set out by a plummet in the axis of the spindle, and a hole, from 10 to 20 inches deep, cut of sufficient width to admit a guide tube, which is set up true and wedged fast. Through this the line of boring tubes works. At first starting, the machine must be run slowly, and under a low pressure, to be increased to the full working speed of 200 to 300 revolutions per minute when the borer begins to cut, a strong and continuous stream of water being kept up from the flushing pump. When, from increasing resistance, the speed begins to slacken, the pressure must be reduced in order to prevent breakage of the boring gear.

The work done by the machine obviously depends upon four quantities, the velocity of rotation, the pressure upon the cutting faces of the diamonds (here called "hydraulic pressure"), the velocity of the circulating current, or "flushing pressure," and the character of the rock. The possibility of varying the first three of these factors within tolerably wide limits, can only be utilised by close observation of the working of the machine in order to detect changes in the character of the rock. In the present instance the work was mainly conducted by reference to the pressure as determined by a gauge attached to the hydraulic cylinders, which was regularly watched by the foreman, who was enabled, by increasing or diminishing the aperture admitting feed-water to the cylinders, to keep the pressure within the limits of 1 to 3 atmospheres, a medium of 2 atmospheres having been usually adopted. In the deepest hole, bored to 206 feet, which was carried out under a pressure of 3 atmospheres, at first by hydraulic pressure and ultimately by the weight of the rods, the total strain upon the boring head was 1,118 lbs. at the beginning and 1,223 lbs. at the end. This appears large when it is considered that it is received by the cutting points of the diamonds, whose section does not exceed a small number of square millimètres, and renders it unlikely that any other cutting agent can be usefully substituted for the amorphous diamond in this class of machine.

Although great care was taken in setting up the machine, it was found that all the holes bored, four in number, deviated from 2° to 4° from the vertical line. This is attributed to the unequal resistance of the strata, which dip at an angle of 17½° across the plane of the shaft bottom to the opposite sides of the cutting head, the deviation being in every case in the direction of the dip.

Of the four holes bored three were abandoned, owing to accidents; these, however, are not considered to be chargeable to the principle of the machine, but rather to weak and defective construction of the working parts.

Bore-hole No. 1 was abandoned at 79 feet, from the core tube breaking in the thread; the attempt to lift by a screwed plug failed through the breakage of the latter.

A similar accident occurred in No. 2 at 190 feet, but the tube was recovered by the plug, and the hole was afterwards continued to 207 feet, at which depth the engine, working at 3½ atmospheres pressure, was no longer able to lift the rods.

In No. 3 the collar of the tube carrying the core clip burst immediately above the boring head, which was lost at 72 feet.

In No. 4, at a depth of 69 feet, four diamonds were torn out of the boring head, which stopped further progress.

With the exception of the last, all these accidents were due to insufficient substance in the tubes at the points of fracture. Nos. 1 and 3 were probably due to a suddenly increased resistance owing to the borer coming across fissures in the strata.

The loss of diamonds is a difficulty that can scarcely be avoided. It is, however, suggested that the rotation of the boring head should always be in one direction, as experience elsewhere shows that a durable setting of the stones is impossible when they are allowed to work both ways.

The actual results obtained were:—

Boring.	Lifting and lowering Rods.	Other accessory Work.	Boring.	Depth.	Average depth bored per hour.
	Hours.	Hours.	Hours.	Feet.	Feet.
No. 1	11·75	32·5	15·5	79	5·08
„ 2	83·50	43·0	25·5	207	8·10
„ 3	11·00	20·5	16·5	72	4·36
„ 4	10·50	17·5	16·0	69	4·30

From this it appears that of the whole time about 30 per cent. is taken up in lifting and lowering the rods, and about 16 per cent. in the actual boring. As the former, however, is proportional to the depth of the hole, it follows that for equal lifting power the advantages of the diamond over other systems of boring, as at present carried out, must disappear in deep borings, as the

actual working time becomes a small quantity as against that consumed in raising and lowering the rods. In order, therefore, to obtain the full advantage of the speedy cutting power of the diamonds under these conditions, it would be requisite either to work with considerably increased lengths of rods, or to substitute solid for tubular cutters, with a continuous system of working. The results obtained in the present instance, however, seem to show that the working power of the machine in its present form has been considerably overestimated. The cost of the four bore-holes, together 130 mètres (426 feet) deep and 1·89 inch in diameter, without charging for machinery, loss of two boring heads, and coals used in providing steam power, has been—

	£.	s.	d.	£.	s.	d.
I. Wages.						
For smith's and fitter's work	22	1	6			
Setting up machine and boring	49	4	6			
				71	6	0
II. Materials.						
Wrought iron (smithy materials)	18	11	3			
Wood and packing materials	60	13	9			
				79	5	0
Making a total of				150	11	0

or about 7*s.* 1*d.* per foot.

In order to obtain a comparison between the machine, and the ordinary plan of using a large number of small holes bored by hand, it may be assumed that for an equal effect two holes of 0·945 inch will be required for each one of those of 1·89 inch made by the machine. The cost of these, supposing that a miner can bore 1 mètre (3·28 feet) in depth per shift at 4*s.* wages, will therefore be $130 \times 2 \times 4 = 1{,}040s. = £52$, or only one-third of those bored by the machine.

It is evident, therefore, on the ground of cost, that the system, even making every allowance for increased speed, reduced wages consequent upon the use of several machines, and increased skill in the workers, is not likely to be one that can be advantageously adopted in practice.

H. B.

Gas Wells in Pennsylvania. By Lawrence Smith.

(Annales de Chimie et de Physique, vol. viii., p. 566.)

When sinking wells in the oil regions of Pennsylvania it has frequently, during the last few years, been found that large volumes of gas would be violently thrown up, sometimes mixed with petroleum and sometimes alone, but it is only quite recently that this gas has been applied to useful purposes.

The most remarkable instances of this phenomenon are the "Delamater," and the "Burns" wells, both 5⅝ inches in diameter, in Butler County, lat. 40° 30′, long. 80°, at about 35 miles from Pittsburg. The Delamater well, on reaching the third sand-rock, produced oil at the rate of 350 gallons per diem, but on its being continued to the depth of 1,600 feet, where the fourth sand-rock was reached, gas alone was ejected, as occurs at the Burns well, which is of the same depth and at a distance of about ½ mile from the former. There are other gas wells of less importance in the neighbourhood, and the "Harvey" well supplies gas to two ironworks in Pittsburg, to which it is conveyed in pipes, a distance of 15 miles.

The quantity of gas ejected from the Delamater well is extraordinary. It issues with a pressure of 100 lbs. per square inch, at a velocity of 1,700 feet per second; and the volume so ejected is calculated to amount to 289 cubic feet per second, or, in round numbers, to 1,000,000 cubic feet per hour. The Author infers from this calculation, that about 1,408 tons of gas issue daily from the Delamater well alone, and estimates it to be, for heating purposes, equivalent to a daily supply of 3,000 tons of coal; but there is some exaggeration in these figures, for, allowing 30 cubic feet of gas to the lb., the weight of 24,000,000 cubic feet would be 357 tons of gas per diem.

As shown by the following table, the gas is chiefly carburetted hydrogen or marsh gas; its illuminating power is stated to be 7½ candles, and its calorific power 25 per cent. greater, weight for weight, than that of good coal gas.

Chemical Constituents.	Burns Well, Butler County.	Lechburg Well, Westmoreland County.	Harvey Well, Butler County.	Cherry-tree Well, Indiana County.
Carbonic acid	0·34	0·35	0·66	2·21
Carbonic oxide	traces	0·26	..	..
Carburetted hydrogen	..	0·56	..	..
Hydrogen	6·10	4·79	13·50	22·50
Marsh gas	75·44	89·65	80·11	60·27
Ethylene	18·12	4·39	5·72	..
Oxygen	..	..	..	0·83
Nitrogen	..	..	..	7·32
	100·00	100·00	99·99	10·

[1] The figures in this column agree with the original.—Sec. Inst. C.E.

The gas from the Delamater well supplies both light and fuel to the surrounding neighbourhood, including the town of St. Joe, and some of it is conducted through a pipe to the cylinder of a powerful engine, which is worked by the pressure of the gas alone; but it is chiefly got rid of by conveying it to several different points where it is burnt in columns of flame, which rise to a height of from 40 feet to 70 feet. The roar of these flames makes it almost impossible for the workmen to hear each others' voices, and it may be distinguished on calm nights at a distance of 15 miles; at 4 miles from the well the noise resembles that of a railway train rumbling over a bridge near at hand.

Some of the gas is conducted as far as Freeport, a distance of 15 miles, through a tube 2 inches in diameter. The pressure in this small tube, when leaving the well, is 200 lbs. per square inch, which is reduced to 125 lbs. by the time it reaches Freeport. The Author infers that it might be taken through a 5⅝-inch tube to Pittsburg (35 miles) without reducing the pressure below 50 lbs. per square inch, and states that a company has been formed with a capital of £100,000 for this purpose.

The Burns well has now been supplying gas uninterruptedly for three hundred days, and although the volume is only half that of the Delamater well, the Author estimates its production during that period as equivalent to 300,000 tons of bituminous coal. Similar wells have continued to eject gas during twelve years without any apparent diminution; and at Fairview there is a well which has uninterruptedly furnished the fuel to more than one hundred engines during the last five years, and continues to this day just as productive as when it was first tapped.

Messrs. Spang-Chalfant and Co. and Graff-Bennett and Co. employ the gas from the Harvey well, before mentioned, in their ironworks at Pittsburg, and use it principally in their puddling furnaces; the results being a great economy of time and a superior quality of iron. Two companies have recently been formed to bore for gas in the town of Pittsburg itself.

O. C. D. R.

The Mining and Metallurgical Produce of Austria in 1875.

(Oest. Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 293.)

The following details are taken from statistical tables recently published by the Austrian Ministry of Trade and Agriculture. The quantities, except where otherwise stated, are given in metrical tons (1,000 kilogrammes), and the values are computed at the exchange of 10 gulden per pound sterling.

1. Mineral Produce.

Ore.	Tons.	Value. £.
Gold	110·2	1,160
Silver	8,068·8	240,480
Mercury	32,797·5	101,356
Copper	5,551·3	28,480
Iron	704,984·3	273,369
Lead	6,888·5	101,289
Nickel and Cobalt	112·0	2,466
Zinc	25,728·5	40,151
Tin	2,020·8[1]	—
Bismuth	5·25	—
Antimony	421·6	4,994
Arsenic	11·2	11
Uranium	6·4	471
Wolfram	36·6	220
Pyrites	12,543·8	11,278
Manganese	10,690·2	13,125
Shale.		
Alum and Copperas	124,241·7	8,185
Asphalt	154·6	174
Petroleum	614·2	6,824
Graphite	20,316·7	45,058
Lignite	6,851,265·6	1,542,450
Coal	4,549,623·6	1,858,822

The total value of the minerals raised was £4,284,599, a diminution of £343,341, or about 7·4 per cent., on that of 1874. The output of lignite is 6·9 per cent., and of coal 1·75 per cent., above that of 1874; but the values have diminished 4·67 per cent. and 11 per cent. respectively. The lignite mines have suffered less from the general dullness of trade than those producing the more expensive coals of the coal measures. The iron ore raised fell off 201,500 tons in quantity, and £96,772 in value, as compared with 1874. The total number of concessions in force at the end of the year was 50,504; 12,285, or 20 per cent., less than at the same period of 1874. Only 9,613 new concessions were granted, being 6,782, or 41 per cent., below those of 1874. The total number of hands employed in mining, for all kinds of minerals except salt, was 83,581, being 3,850, or 4·4 per cent., fewer than in the preceding year. Their occupation was distributed as follows:—

	Men.	Women.	Children.	Total.
Coal mining	31,922	2,402	950	35,274
Lignite „	24,546	1,879	200	26,625
Iron ore „	7,270	166	193	7,629
Other „ „	12,347	1,206	500	14,053
Totals	76,085	5,653	1,843	83,581

[1] Not ore, but tin stuff as broken from the lode; by comparison with Table 2 it would appear to have been about 176 lbs. of metallic tin to the ton.—H. B.

In addition to these there were engaged in salt mines and works 5,792 men, 1,544 women, and 1,469 children, together 8.805 hands, being 425, or 4·6 per cent., less than those of 1874. There were 388 cases of injuries from accident, classified as follows, distinguishing fatal and serious accidents :—

	Coal mines.	Lignite mines.	Iron ore.	Other ores.	Salt.	Totals.
Fatal accidents . .	112	58	4	19	7	200
Serious injuries . .	79	52	13	31	13	188

2. Metallurgical Products.

	Quantities.	Value. £.	s.
Gold	436 oz. troy	1,534	10
Silver	798,886 „ [1] „	228,226	4
Mercury	647,460 lbs.	154,846	4
Copper	394 tons	37,808	12
Litharge	2,976·6 „	68,169	14
Lead	4,133·4 „	105,504	4
Forge pig iron	262,274·0 „	1,463,501	0
Foundry „	41,185·2 „	329,382	10
Nickel	48,272·0 lbs.	4,723	0
Tin	159·9 tons	15,662	10
Zinc.	2,940·0 „	68,472	2
Antimony	74·0 „	2,907	12
Arsenic	4·4 „	107	6
Sulphur	946·6 „	8,226	16
Copperas	1,211·6 „	3,781	14
Alum	1,718·5 „	13,900	14
Uranium (yellow)	10,130·4 lbs.	9,863	12
Mineral colours (ochres) . .	8·0 tons	24	0

The total produce of the smelting works was valued at £2,516,642 4*s*., being £366,610 12*s*., or 12·7 per cent., less than that of 1874.

The diminution in production of forge pig iron was 28,391 tons on the preceding year, or 9·75 per cent., the fall in value being £312,208 6*s*., or 17·5 per cent. In foundry iron the corresponding reductions were 307 tons, or 0·74 per cent., and £30,705 8*s*., or 8·5 per cent. The average price of the former class of pig metal fell from £6 2*s*. 3*d*. to £5 11*s*. 8*d*. per ton, and of the latter from £8 13*s*. 8*d*. to £8. The total falling off in this particular branch of iron industry was 8·6 per cent. in quantity, and 16 per cent. in value, as compared with 1874.

The total number of hands employed in metallurgical works was 10,438, including 9,762 men, 435 women, and 241 children, or 294 (2·7 per cent.) less than in 1874. Of this number, 8,224 men, 347 women, and 216 children were engaged on works producing pig iron.

H. B.

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[1] The original has 24,848 tons, which is obviously about a thousand times too high.—H. B.

The Mineral Produce of the Prussian States in the year 1875.[1]

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, vol. xxiv., part 2, pp. 21–75.)

Coal and Iron Ore Mining.—The number of collieries at work during the year was four hundred and forty-eight, besides thirty-two new winnings and suspended workings. Of lignite mines, five hundred and twenty-nine were working, and eleven opening out, or stopped. Iron ore was raised in seven hundred and eighty-seven mines, and one hundred and eighty-six others were stopped. The production of these three staples was as follows:—

Mineral.	Quantity.	Colliery Consumption.	Number of Workpeople.			
			Underground.	Surface.		Totals.
				Men.	Women.	
	Tons.	Tons.				
Coal . .	33,419,295	2,389,264	127,117	30,386	2,199	159,702
Lignite .	8,340,259	620,071	10,593	7,835	110	18,538
Iron ore .	2,595,130	..	15,412	4,935	1,309	21,656

The quantities are given in metrical tons of 1,000 kilogrammes. The average production per hand employed underground was—

Of coal	263	tons per annum.
„ lignite	787	„
„ iron ore	168	„

The value of these minerals at the place of production was—

		s.	*d.*		*s.*	*d.*		*s.*	*d.*	
Coal,	maximum	13	2	minimum	6	0	average	7	7½	per ton.
Lignite	„	13	9	„	2	2¼	„	3	6½	„
Iron ore	„	14	2	„	2	8	„	7	6	„

The produce of the ores of the more important metals other than iron was—

Mineral.	No. of Mines.	Quantity.	Average Value per ton.			Hands employed.			
						Under-ground.	Surface.		Totals.
		Tons.	£.	*s.*	*d.*		Men.	Women.	
Zinc . . .	68	465,210	1	7	2	5,063	1,874	1,307	8,244
Lead . . .	146	107,878	9	13	0	9,594	7,368	915	17,877
Copper . . .	26	273,954	1	5	2	5,480	1,115	8	6,603
Silver and gold	..	6	625	14	0	Included in lead.			..
Nickel . . .	2	222	7	19	2	10	6	..	16
Cobalt . . .	3	200	19	15	9	78	5	..	83
Arsenic . . .	2	2,303	1	16	0	37	42	..	79
Manganese .	50	12,059	2	4	5	328	158	57	543
Iron pyrites .	..	123,977	1	0	7	502	438	..	940

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 390, for similar statistics for 1874.

The total produce of metallic ores of all kinds was 3,612,471 tons, valued at £3,139,525, or an average of 17*s.* 2*d.* per ton all round.

Rock salt was raised in six mines, employing 280 hands, and producing 80,408 tons, valued at £26,721; potash salts in two, by 594 hands, to the extent of 162,661 tons, worth £60,144. In addition to these quantities 217,926 tons of salt were obtained in salt works, by boiling down brine.

The number of fatal accidents in mines of every description, was 587 out of a total of 239,722 work-people employed, or 1 death per 408 hands—an unfavourable increase on the preceding year, when the proportion was 1 to 411.

The number and proportion of accidents in the different classes of mines was—

In coal mines,	454,	being 1 per	354	hands, or 1 per	73,833	tons raised.
Lignite	,,	43,	,,	452	,,	193,959	,,
Metal	,,	79,	,,	668	,,	39,171	,,
Other	,,	11,	,,	789			

The principal causes of accident in coal mines and the loss of life attributable to each were—

1. Fall of ground, 155.
2. Explosions of fire-damp, 28.
3. Accidents in blasting, 25.
4. Accidents in shafts and inclines, 151.

Metallurgical Preduce.—Of the total number of 339 blast furnaces for smelting iron ore, 129 were cold, the remaining 210 were blowing for a period of 1,931½ furnace-months, giving an average period of blast of 9⅛ months per furnace. The iron-producing materials smelted were—

	Tons.
Iron ores, inland	3,315,636
,, foreign	219,080
Forge and mill cinders	148,238
Scrap and washed iron	248
Total	3,683,202

The total make of pig iron was 1,398,337 tons, equal to an average of 167 tons per furnace per week, or a considerable increase on the preceding year, when the weekly average was only 140 tons.

Of the above amount 92,028 tons were returned as smelted from imported ores.

According to fuel employed, the blast furnaces were classified as follows:—

Fuel.	Number of Works.	Number of Furnaces.	Foundry Pig and Castings.	Forge Pig.	Steel-makers' Pigs.	Average weekly Make.
			Tons.	Tons.	Tons.	Tons.
Coal and coke .	74	141	72,739	1,025,235	226,612	228
Charcoal . .	59	60	44,008	11,367	2,051	25¼
Mixed . . .	9	9	2,847	13,554	44	57⅔

As compared with the previous year, the weekly make of furnaces on mineral and mixed fuel, had increased from 204 tons and 49½ tons, while those on charcoal showed no difference.

The total number of hands employed in the production of pig iron and first-fusion castings, was 18,001, including 594 women, a diminution of 1,000 on the numbers of the preceding year.

The total consumption of pig iron in 1875 was as follows:—

Purpose.	Inland.	Foreign.	Together.
	Tons.	Tons.	Tons.
Foundry use	83,675	207,688	291,363
Malleable iron	1,091,432	29,741	1,121,173
Crude steel (forge processes) .	111,681	28,226	139,907
	1,286,788	265,655	1,552,443

Add castings run from blast furnaces	31,219
Pig iron used in the production of 261,091 tons of crude steel produced in cast steel works, estimated at 100 of pig-iron per 70 of steel	372,987
Making a total consumption of	1,956,649
The produce of the blast furnaces was	1,398,337
Leaving an excess of consumption over production without allowing for export or stock	558,312

In 1874 the corresponding excess was 785,635 tons.
In 1873 „ „ 426,991 „

The number of mills and forges was 159 working upon pig iron, and 140 upon scrap and purchased blooms. The former class included 1,382 puddling furnaces (against 1,469 in 1874), and 71 open finery fires (90 in 1874). The yield of a puddling furnace varied in the different districts from 100 tons to 846 tons of blooms per annum, the average being 593 tons. The production of an open fire was from 31 tons to 1,100 tons, with an average of

392 tons. The puddling and finery forges consumed 1,121,173 tons of pig iron, including 29,741 tons of foreign make, and produced 832,849 tons of finished iron and blooms. The forges produced from 90,128 tons of scrap and waste iron, and 103,780 tons of puddled bars and blooms, 146,861 tons of finished iron, an amount that includes 8,943 tons made in charcoal fires. The total amount retained for the use of the works in both classes of mills and forges was 15,570 tons.

The steel works were classified under two heads, 37 being returned as crude steel works working upon pig iron and selling a portion of their produce as blooms, and 43 as cast steel works making only finished products. The former worked up 139,890 tons of pig iron, including 28,226 tons imported, and produced 110,254 tons of blooms and finished steel, retaining 1,137 tons for their own use. In the cast steel works the production of finished steel was 240,881 tons, including 2,445 tons used in the works.

The produce of steel, classified according to the processes employed, was as follows:—

Process.	Number of Furnaces.	Total Product. — Tons.	Average per Furnace per Annum. — Tons.
Puddling	348	113,250	325
Open fire	9	368	41
Bessemer	45	235,592	5,235
Martin-Siemens	27	15,728	583
Cementation	2	58	29
Crucible	73	11,784	161

The production of finished iron and steel, classified according to uses, was as follows:—

	Iron. — Tons.	Steel. — Tons.	Together. — Tons.
Rails and fish plates	140,781	228,302	369,083
Bridge and girder iron	65,626	..	65,626
Railway wheels, tires, and axles	11,465	47,480	58,945
Heavy special plates and forgings	25,899	6,945	32,844
Artillery and projectiles	..	6,068	..
Black plates and sheets	104,655	2,862	..
Tin plates	6,236	..	..
Wire	112,842	153	112,995
Tubes	2,385	..	..
Other kinds	383,669	36,793	420,462

The number of persons employed in the different classes of iron and steel works was—

	Men.	Women.
Blast furnaces	17,392	594
Foundries	27,453	142
Puddling forges and mills	35,418	364
Blooming "	5,702	20
Crude steel works	3,042	3
Cast steel works	15,425	..

The value of the various kinds of iron and steel was £1,525,970. The other metallurgical products were—

Metal.	No. of Works.	Hands employed.	Quantity smelted from Native Ore.	Quantity smelted from Foreign Ore.	Together.	Value.
			Tons.	Tons.	Tons.	£.
Zinc . .	32	6,555	70,726	3,392	74,118	1,539,296
Lead and Litharge .	17	2,656	56,885	8,527	65,412	1,413,215
Copper, partly blister copper and regulus . .	8	1,355	7,055	157	7,212	637,686
			lbs. (German.)	lbs. (Germ.)	lbs. (German.)	
Silver . .	2	344	202,436	22,305	224,741	941,042
Gold . .	..	..	291	62	353	24,328
			tons.	tons.	tons.	
Nickel, partly regulus . .	4	140	99·06	137·75	236·81	83,246
			cwt. (50 k°.)	cwt.	cwt.	
Cobalt colours .	1	14	36	190	226	603
			lbs. (½ k°.)			
Cadmium .	..	..	3,837	..	..	1,601

There was no production of mercury, tin, antimony, bismuth, or uranium, during the year.

H. B.

Puzzuolana of St. Paul in Rome, and that of Maremma in Tuscany. By A. Cavazzi.

(Ingegneria Civile e le Arti Industriali, vol. xxiv., p. 50.)

The analysis of the Puzzuolana of St. Paul, justly appreciated for its properties in submarine constructions, was first given by Vicat, and afterwards by Wagner. Neither of these, however, gives an analysis of the substances considered essential for solidification and hardening.

Hitherto little has been known about the composition of the puzzuolana of Maremma, in Tuscany. This material is of a brick-red colour, much lighter than that of St. Paul, and is sold in commerce in a powdered state, which differs but little from the latter. It belongs to the category of volcanic puzzuolanas.

In the following list the Author compares the results obtained by his own analysis with those given by Vicat, having taken care to conduct his analysis in exactly the same manner.

COMPOSITION of the PUZZUOLANA of ST. PAUL in ROME.

		(Vicat.)		(Cavazzi.)
Silicon		45·00		45·500
Aluminium		14·80		15·125
Calcium		8·80		9·336
Magnesium		4·70		3·595
Oxide of iron		12·00		12·050
Potassium	dissolved in hydrochloric acid	not determined		2·154
Sodium	dissolved in hydrochloric acid	not determined		3·782
Soluble and volatile components		14·70	Water and traces of other substances	8·458
		100·00		100·000
Specific gravity		not determined		2·285

The percentage of active principles is also given by Vicat at 73·3 per cent. The slight differences in the analyses may be attributed to the method of testing, and to varieties of different samples of the same deposit.

COMPOSITION of the PUZZUOLANA of MAREMMA in TUSCANY.

Silicon	68·525
Aluminium	12·200
Calcium	0·378
Magnesium	nil
Oxide of iron	7·700
Potassium } soluble in hydrochloric acid	nil
Sodium } soluble in hydrochloric acid	nil
Matters eliminated through calcination	10·700
Loss, &c.	0·497
	100·000
Specific gravity	2·439

COMPOSITION of SOLUBLE and of INSOLUBLE COMPONENTS in the CONCENTRATED HYDROCHLORIC ACID.

The puzzuolanas were heated with this acid for five hours in a sand bath.

	St. Paul.		Maremma.	
	Soluble.	Insoluble.	Soluble.	Insoluble.
Silicon	0·525	44·975	0·325	68·200
Aluminium	14·925	0·200	11·675	0·525
Calcium	8·498	0·838	0·298	0·080
Magnesium	3·172	0·423	..	..
Oxide of iron	11·200	0·850	4·125	3·575
Potassium	2·154	..	..	..
Sodium	3·782	..	..	..
Water and traces of other matters	8·458	..	11·197	..
	52·714	47·286	27·620	72·380

SILICON and ALUMINIUM DISSOLVED after ONE HOUR'S BOILING with a CONCENTRATED SOLUTION of CAUSTIC POTASH.

		St. Paul.	Maremma.
Upon 100 parts of Puzzuolana	Silicon . . .	4·00	0·76
	Aluminium . .	0·66	4·83

The difference in composition shown by these two cements, particularly as regard the quantity of calcium and magnesium, necessitated a fifth experiment, to ascertain the exact proportion of silicon.

		St. Paul.	Maremma.
Dissolved by hydrochloric acid after three hour's boiling	Silicon	traces	traces
	Aluminium . . .	15·012	12·130
	Oxide of iron, calcium, magnesium, potassium, and sodium .	27·910	8·050
Dissolved by potassa, in the remains left in the hydrochloric acid, after one hour's boiling	Silicon	39·940	4·300
	Aluminium . . .	traces	traces
Insoluble in hydrochloric acid and in potassa		8·680	64·820
Volatilised at red heat		8·458	10·700
		100·000	100·000

Fuch's experiences, and those of Winkler, Feichtinger, &c., have shown that the characteristic property of puzzuolanas, as they are mixed with calcium, is essentially to be attributed to this latter base in combination with silicic acid. This combination, under water, gives an insoluble basic hydrate of silica, of great tenacity and hardness. The process of hardening this artificial cement is followed by the separation of potassic hydrate. It was also proved that a solution of soluble glass (silicate of potassium) yields to the calcium its silicic acid, liberating the caustic alkalies, also at the ordinary temperature.

These researches demonstrate the superiority of the puzzuolana of St. Paul, although it should be acknowledged that excellent results in sub-aqueous construction have been obtained with that of Maremma, as proved by the eminent engineer, Ugo Brunelli, who, in 1869, assisted at the breaking down of the old bridge on the Silla, near Porretta. The solidity acquired by this hydraulic material was so great, that part of the plateau, upon which a new foundation was to be built, could only be destroyed by blasting. R. Q.

Report of the Results of a Chemical Analysis of Boiler-stone and Sediment. By PROF. ANTON RÉLOHOUBEK.

(Mittheilungen des Architekten- und Ingenieur-Vereines in Böhmen, vol. x., p. 78.)

The Author, after remarking that, in spite of the numerous discussions on this subject, the problem as to the constitution of

boiler-stone has never been satisfactorily solved, proceeds to give the results of his chemical analysis of the sediment found in a 'bouilleur,' and of the stone in a boiler. The feed-water was taken from an old lignite pit, and, although not specially analysed, was believed to contain the same amount of proto-sulphate and sulphate of iron, and of the sulphates of alumina, lime, and magnesia, as others previously tested.

While the plates of the boiler in question were covered with a thin coating of stone, a friable sediment of the colour of ochre, differing completely, both chemically and physically, from the stone, had collected in the 'bouilleur.'

The boiler-stone, formed in thin scales of 0·5 to 1 millimètre in thickness, was of a reddish-brown outside, and a grey or reddish-grey inside; its specific gravity at 59° Fahr. was 2·594. The Author found also particles of india-rubber, quartz mica, coal, mortar, straw, hair and other immaterial ingredients mixed with it. The specific gravity of the sediment was scarcely 2·005.

The following table gives both the qualitative and the quantitative chemical analyses:—

Every 100 *parts contain*—	*Sediment and*	*Boiler-stone*
Sesquioxide of iron	33·0676	2·9170
Alumina	4·0114	0·1095
Protoxide of manganese	traces	traces
Limestone	0·9378	26·9431
Magnesia	3·1898	2·7491
Potash	traces	0·8446
Soda	traces	0·1785
Silicic acid	0·1991	0·7251
Phosphoric acid	0·0425	0·1974
Sulphuric acid	0·7167	44·2515
Carbonic acid	traces	traces
Chlorine	traces	traces
Fat	traces	0·0921
Other organic matter and chemically combined water	8·3333	9·7168
Hygroscopic water	3·8081	1·1905
Residuum insoluble in hydrochloric acid	45·6633	10·1059
Loss by analysis	0·0304	—
	100·0000	100·0211

A comparison between the quantitative results suggests that the feed-water originally contained clay, fine sand, and organic matter, besides iron and aluminium, because in both analyses a considerable quantity of silicate, sand, and mica was found. The silicates consist principally of alumina with particles of silicates of potassium, sodium, and iron; and these, originally suspended in the feed-water, form nearly half the weight of the sediment, but only 10 per cent. of that of the boiler-stone. In the latter they were not soluble in diluted hydrochloric acid.

The hydro-oxides of iron and aluminium remain a long time in suspension in boiling water, and collect at last at the deepest part,

viz. in the 'bouilleur'; therefore 37 per cent. is obtained in the sediment against 3 per cent. in the boiler-stone, which latter is deposited on the upper surface, in the shape of a brownish-red coating. The reason so small a quantity of limestone and sulphuric acid is found in the sediment is that both are soluble in the form of hydrous sulphate of lime, and are precipitated as a crystalline coating on the boiler-plates, to which, during the conversion of water into steam, they adhere.

One part of hydrous sulphate of lime is soluble in five hundred times its weight of water of ordinary temperature, the quantity of water necessary increasing with the temperature. On account of the greater solubility of chemical combinations of the alkalies with sulphuric acid, 1 per cent. of the same is found in the boiler-stone, and only traces in the sediment. Because the sulphuric acid is not sufficient to dissolve all the magnesia as sulphate, and there is no other acid, the magnesia is precipitated as hydro-oxide of magnesium, and is found in the sediment. For the same reason the boiler-stone contains more silicic and phosphoric acid than the sediment. The presence of fat is accounted for by using the waste steam to warm the feed-water. The great hygroscopic properties of the sediment arise from its crystalline and pulverous formation.

After examining the active composition of the sediment, and that of the boiler stone, the Author arrives at the following tabular result:—

Every 100 *parts contain*—	*Sediment and*	*Boiler-stone*
Hydro-oxide of iron	36·7877	3·2514
„ aluminium	4·7126	0·1286
Phosphate of calcium	0·0928	0·4298
Sulphate „	1·2184	64·8688
Oxide „	0·3858	—
Hydro-oxide of magnesium	4·6252	0·2554
Sulphate „	—	7·7190
„ potassium	—	1·5617
„ sodium	—	0·4088
Silicic acid	0·1991	0·7251
Fat	—	0·0921
Other organic matter and water	2·4766	9·2840
Hygroscopic water	3·8081	1·1905
Residuum insoluble in hydrochloric acid	45·6633	10·1059
Loss by analysis	0·0304	—
	100·0000	100·0211

The sediment then in the 'bouilleur' consists principally of a mixture of hydro-oxide of iron and silicates, insoluble in dilute hydrochloric acid, which were originally in suspension in the feed-water. Small quantities of hydro-oxide of aluminium and magnesium appear, while the other ingredients must be looked upon as accidental.

The boiler-stone, on the other hand, consists principally of anhydrous sulphate of calcium, and about 10 per cent. of other

sulphates, such as magnesium, potassium, and sodium. The silicates (principally silicate of alumina) insoluble in hydrochloric acid, the fat, the organic matters, as well as the hydro-oxides of iron and aluminium, must be considered secondary ingredients.

W. E. T.

On Frozen Dynamite. By Capt. Philip Hess.

(Mittheilungen über Gegenstäude des Artillerie und Genie Wesens, 1876, pp. 1–20.)

Nobel's blasting oil belongs to the numerous class of artificial products, extensively used for industrial purposes, of which the physical and chemical qualities are scarcely understood. But the small number of experiments which have been instituted to bridge over the gaps in the knowledge of so dangerous an explosive can hardly be a matter of surprise.

The difficulty of such a study chiefly arises from the fact that it is rarely possible to time the stages in the combustion of the explosive.

The use of Nobel's material, and especially that of nitro-glycerine when frozen, has greatly added to the above difficulties. The freezing point of nitro-glycerine varies between 39° Fahr. and 53·6° Fahr., and this arises from the differences in manufacture and the varying nature and action of the oil under cold. Respecting the first cause, the Author's investigations show that the oil usually sold never contains 18·5 per cent. of nitrogen, the quantity necessary for tri-nitro-glycerine; therefore in the oil at least two kinds of nitric ether must be assumed to be present; but, on the other hand, there may exist all the three ethers theoretically possible, viz., mono-, bi- and tri-nitro-glycerine; this fact will explain some peculiarities which would otherwise seem paradoxical. The Author begins by tabulating briefly observations made in respect of this matter.

The blasting oil, when free, will bear sometimes for days low temperatures without solidifying. Samples from Nobel's factory in Zamky remained liquid in the Military Laboratory under temperatures varying between 32° and 17·6° Fahr.

Blasting-oil samples would not, it was found, solidify when exposed even for hours to cold varying from 10° to 5° Fahr., according to Champion. Dr. Gladstone has noticed that nitro-glycerine, when subjected to cold produced by strong carbonic acid and alcohol, will only become thick or glutinous without freezing.

From experiments in the Author's laboratory, it was found that in a considerable quantity of nitro-glycerine, exposed for several days to a temperature between 50° and 32° Fahr., some crystals had detached themselves, remaining for a time floating in the oil, which did not itself congeal.

Contact with absorbent substances, such as a silicious marl, undoubtedly hastens the freezing of the nitro-glycerine in temperatures below 53° Fahr.

Nitro-glycerine, when fluid, renders the silicious admixture pellucid, but when frozen it loses this power; so that thoroughly congealed nitro-glycerine appears no longer flesh-coloured or brown, but white. This peculiarity indicates whether a dynamite cartridge is frozen completely. For this it must be broken, which, according to Mowbray, can be done without danger.

If a cartridge is exposed for a day in a parchment box the oil will completely freeze in a temperature below 10° Fahr., if the cartridge has not a greater diameter than 1 inch.

If dynamite is spread over metal plates 1 millimètre thick, half an hour's exposure produces solidification. When blasting oil and nitro-glycerine powder are frozen, and then subjected to shocks which would explode them in a softer state, peculiar variations ensue. The general result of the trials showed that nitro-glycerine and blasting preparations formed from it become less sensitive to mechanical shocks directly the nitro-glycerine contained in the preparation is completely frozen. During the experiments made by the Military Committee, the preparations in question (silicious dynamite being chiefly dealt with when the temperature of the surroundings did not exceed 10° Fahr.) were cooled by artificial means (mixtures of snow and common salt being used), the temperatures obtained being between 1·4° and 69° Fahr., and at which the samples were kept and completely frozen.

Under these conditions the silicious dynamite showed the least liability to explode when tried with a capsule filled with fulminate of mercury, employed to bring about combustion with safety; for the similar reason a cartridge made of gun-cotton and nitro-glycerine was effectively made use of.

With dynamites composed of absorbent matters having a combustible tendency, it was noticed that the diminution in liability to explode was rather lessened when frozen; for example, this was the case with Nobel's dynamites Nos. 2 and 3, where the absorbent material is composed of wood and saltpetre, or with the gun-cotton and dynamite before alluded to. Cartridges of this last-mentioned material exploded, when not frozen and frozen, with the same effect, from the initial shock of the mercury capsule before referred to, when this last contained 9·25 troy grains of chlorate of potash.

Silicious dynamite, when fired at, and soft dynamite, when freely exposed, would not explode when struck with a bullet from the old form of rifle at a distance exceeding 2,500 paces; at 2,000, combustion was produced. Frozen dynamite, however, would not explode even at 60 paces. The Author gives details of the trials by striking or ramming dynamite samples, which were carried out by the Military Committee.

The various preparations were in layers of 1 millimètre high each, and placed on a plate of 1·34 square centimètre, where they were struck perpendicularly above and below by a steel hammer,

the force of the blow being regulated by the amount necessary to explode the sample. Silicious dynamite exploded, when soft, with a blow of 0·75 kilogrammètre; but when frozen this force was increased to 1 kilogrammètre, and one blow sufficed. Under similar conditions gun-cotton dynamite, when not frozen and frozen, required blows of 0·5 and 1·25 kilogrammètre respectively. With nitro-glycerine powders in a transition state of freezing, the force of the stroke producing combustion is not sensibly increased until complete congelation sets in. With samples in a transition state, explosion is produced at a second or third blow, when the force is less than would be required to effect combustion at a single stroke, and these light blows may be repeated until the strength of the preparation is so much reduced that no result after a time ensues. The limit between explosion and non-explosion is considerable; but when in a soft state the tendency to combustion is more defined.

The results of the Committee's trials are shown in the following table; the weight is 11 lbs., the dynamite being not frozen:—

Fall,	19·7 inches		Explosion.
„	15·7 „		„
„	11·8 „		„
„	7·9 „		„
„	5·9 „		„
„	5·9 „		„
„	5·9 „		„
„	3·9 „		No explosion.
„	3·9 „	2 blows	„
„	3·9 „	3 blows	„

Experiments with dynamite in a transition state, between liquid and frozen:—

Fall,	19·7 inches		Explosion.
„	15·7 „		„
„	11·8 „		„
„	7·9 „		„
„	5·9 „		„
„	3·9 „		No explosion.
„	3·9 „	2 blows	Explosion.
„	2·0 „		No explosion.
„	2·0 „	2 blows	Explosion.
„	1·6 „		No explosion.
„	1·6 „	2 blows	„
„	1·6 „	3 blows	„

The sensibility of frozen nitro-glycerine to mechanical shocks is shown by these experiments to be less than that of non-frozen nitro-glycerine. In the transition state, however, this sensibility is still further increased, especially in respect to repeated light shocks, such as those accruing through the operation of packing for transport; the experience both of the laboratory and the factory confirms this view.

In dynamite factories, most accidents take place upon the filling

of the cartridges with the nitro-glycerine powder, and when the temperature of the atmosphere fluctuates. To obviate this difficulty, the sheds where the cartridges are made are now heated with water, as the agent best fitted to distribute the temperature equably, the unequal heating caused by ordinary fires being a source of danger.

Mowbray first proved, on a large scale, that dynamite can be carried about, shaken, or broken, with impunity when in a frozen state; and experiments have been instituted to show whether powdered nitro-glycerine in a free state behaves differently from the liquid at low temperatures. Experience proves that with oil in a powdered form congelation takes place more easily than when free, owing, perhaps, to its greater cohesion. It must, however, be remembered that with oil combined with absorbent materials the latter are bad conductors of heat, and therefore a greater degree of cold is required to solidify them. Chemical analysis also proves that nitro-glycerines contain different ratios of nitrogen, and for that reason they have different freezing capacities. It should be remembered, too, that glycerine will only solidify under $-40°$ Fahr., and that Ott lays down the highest point at which rigidity is possible at 53° Fahr.; it should, therefore, be allowed that the freezing point of any three possible nitrates lies between 53° and 40° Fahr. As a rule, in a mixture of different fluids, the one least sensitive to cold prevents the others from freezing, so that the zero point of tri-nitro-glycerines is reduced, according to the quantitative relations of the three nitrates. Several facts tend to elucidate the manner in which nitro-glycerine crystals are formed, which partially influence the cohesive strength of nitro-glycerines when in a powdery form.

Frozen dynamite, as a rule, secretes a portion of its oil when thawed; a portion collects in the lower part of the silicious marl and renders it extremely fatty, sometimes causing a deposit. When thoroughly thawed, re-absorption of this oil sometimes takes place. The above series of experiments show that dynamite, in a transition state, more easily emits nitro-glycerine when under pressure than it does in a soft condition.

If silicious dynamite be placed under water, the oil is separated, owing to the greater affinity of the water to the marl, and at the moment of separation it is more easily frozen, a fact which was proved in the laboratory.

When all these facts are combined, it seems to show a series of harmonising observations, such as the comparative absence of danger in handling large masses of frozen dynamite, its insensibility to the shocks from a gun or a hammer, and to the mechanical caloric impulses of the initial explosion. The result to be deduced seems to be, that with nitro-glycerine in general, and therefore, probably, in each of its three gradations, it is more indifferent to shocks, both mechanical and caloric or chemical, when in a frozen than a fluid state; although it remains to be proved whether it is so under all circumstances, in particular

whether well-formed nitro-glycerine crystals are able to resist destructive impulses equally well in all directions of cleavage.

With the oils of commerce, as a rule, congelation takes place partially, and under the influence of lengthened cold the process of thawing is slow and gradual; in practice, it is difficult to determine whether nitro-glycerine powder is wholly frozen until it has been observed and exposed for a considerable time. Such portions of the oil as are frozen seem to alter the relations of cohesion of those portions still fluid with their absorbent material, so that this absorbent seems only feebly able to retain the fluid portion at the now reduced surface. These parts being no longer protected as before by their surrounding absorbent material, are merely loosely embedded between inelastic frozen hard particles, and evidently are more exposed to mechanical impulses than when the whole of the material is in a state of complete solution. The less the absorbent quality of the mixing powder, and the less it has taken up, the more its cohesion has been reduced by the presence of moisture, and, therefore, the more easily the oil will be secreted, and the greater consequent danger during manipulation; this may, it is true, be much reduced by a superabundance of the absorbent, and by well-dried powder mingled with it; but the danger will exist during the greater part of the cold season, owing to the single cohering particles having but a weak heat-conducting power. The Author insists much on the necessity for equally heating all laboratories where nitro-glycerine is handled. It is certain, from these investigations, that frozen dynamite is less liable to explode than when it is fluid, and that it is more sensitive still in a semi-condition, especially in respect of continuous mechanical impulses. The natural reticence of manufacturers has prevented authentic statistics of accidents and their causes being formed, and consequently a rational code of restrictions on the manufacture and transport of this dangerous material has not yet been devised; but the Author strongly urges the importance of the appointment of good technical chemists to superintend and inspect manufactories, &c., and considers the appointment of untrained government officials highly injurious to the public interest.

H. T. M.

The Electric Light in Navigation. By Hippolyte Fontaine.

(Revue Industrielle, vol. vii., p. 242.)

The steam-packet "Amérique," belonging to the General Transatlantic Company, has, since the end of March, 1876, been provided with a Gramme machine and the apparatus necessary for the production of the electric light. The introduction is due to M. Eugène Pereire. Experiments were in the first instance made by Commander Pouzoly, during a voyage from Havre to New

York and back, and these being attended with great success, the system was employed also on board the "France" and the "Ville de Brest." The light has been found chiefly of use in preventing collision, in facilitating entry into port, in discharging and taking in cargo by night. The apparatus used on board the "Amérique" consists of a lighthouse, an electric generator, a portable lamp, and several accessories. The lighthouse is at the summit of a sheet-iron turret, from the inside of which it is accessible without the necessity of passing on to the bridge. The turret as first erected was 23 feet in height, but this, for greater stability, was reduced to 6½ feet. The diameter of the turret is 3 feet 3 inches, and it is situated in the fore part of the vessel, about 50 feet from the stem. The beacon is of prismatic glasses clearing an arc of 225°, leaving the vessel nearly wholly in the shade. The magneto-electric machine gives a light equal to about 200 Carcel burners and weighs nearly 4 cwt. It is worked by a three-cylinder engine at a velocity of 850 revolutions. A well-insulated cable connects the machine with the lamp in the beacon or with a movable lamp. It is unnecessary that the lamp should burn continuously, and arrangements are made by which the circuit is completed at the will of the officer in command. For general purposes of navigation, an intermittent or flashing light gives the best results; and the necessary interruptions have been arranged by a revolving circular commutator of copper and wood, which produces 20 seconds' light and 100 seconds' eclipse, due allowance being made for maintaining the equilibrium of the current during the extinction and action of the light. The height of the luminous focus is 32·8 feet above the water-level, and the carrying power of the light, having regard to the depression of the horizon, is 10 nautical miles (18,520 mètres) for an observer whose eye is 20 feet above the water-line. The system appears to have met with much favour, and will probably be extended. P. H.

Extension of Carnot's Thermo-dynamic Theorem to Electrical Phenomena. By G. Lippmann.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1425.)

The first principle of the mechanical theory of heat has, it is known, been extended to electrical phenomena; but the extension has not been carried to the second principle. The latter is understood to be the solution of the following problem:—To find the conditions to be fulfilled, so that the result in mechanical work from a heat-machine shall be a maximum. The Author proposes the solution of this problem for electro-motors; that is, to find the conditions of maximum result for these motors. In the production of mechanical work may be utilised the re-establishment of electric equilibrium; that is, the passage of a certain

quantity of electricity from a point of higher potential to a point of lower potential. Whatever may be the form and principle of the electro-motor, the Author insists that its yield of work is a maximum only when the condition is fulfilled, that at each point and at each instant of operation electric equilibrium may be established. This condition necessary to a maximum, the existence of electric equilibrium at each instant of work, may be expressed thus:—In order to give maximum work-result, it is necessary that the motor be "reversible." If $\int d\,m$ be the algebraic sum of the quantities of electricity given by the several reservoirs for the working of the motor, in all motors for which $\int d\,m = 0$, the work is a maximum. In coupling two such motors in inverse direction the work yielded will be nil, and could not be otherwise unless the apparatus realised perpetual motion. The expression $\int d\,m = 0$ has another and simpler interpretation; it shows that the electricity may displace itself, but cannot vary in quantity. This principle of the conservation of the quantity of electricity has been admitted in all known cases of induction, friction, &c. The equation $\frac{d^2 V}{d\,x^2} + \frac{d^2 V}{d\,y^2} + \frac{d^2 V}{d\,z^2} = 0$, has precisely the same signification in the case of a constant current. It may besides be shown that this equation, $\int d\,m = 0$, has the same form as Clausius' equation, $\int \frac{d\,Q}{T} = 0$. It is evident that if V be the potential of an electric reservoir, and E its electric energy $\left(E = \Sigma \frac{m\,m^1}{r}\right)$, the equation $\int \frac{d\,Q}{T} = 0$, has its analogue $\int \frac{d\,E}{V} = 0$. As $V = A\,m$ and $E = \frac{1}{2} A\,m^2$, A being a particular constant for each reservoir, and m its charge, it follows that,

$$\int \frac{d\,E}{V} = \int \frac{A\,m.d\,m}{A\,m} = \int d\,m \text{ identically.}$$

That $\int d\,m = 0$ may obtain for all complete cycles, it is necessary that $d\,m$ should be a perfect differential. The equations which express this condition, together with the analogous equations of the principle of equivalence, constitute the more general differential equations of a reversible electric system. These are equally satisfied in the cases of equilibrium and of movement, because for an exact reversible system the conditions of equilibrium are satisfied at each instant of movement.

P. H.

On the Electric Conductivity of Manganic Oxides and various Carbons. By W. Beetz.

(Poggendorff's Annalen der Physik und Chemie, vol. clviii., p. 653.)

The determination of the conductivity of these materials, which are largely used in the construction of some kinds of batteries, is of importance. In the following table the Author gives the conductivity of various manganese ores and kinds of carbon, the standard being mercury = 1 :—

Substance.	Conductivity; mercury = 1.
1. Manganite	0·0000016 0·0000026
2. Pyrolusite	0·000123 0·000230
3. Nuremberg battery carbon	0·00017
4. Stick of Faber's graphite	0·00455
5. Munich retort carbon	0·0110
6. Ruhmkorff's carbon plate	0·0138
7. Duboscq's carbon point	0·0288

The stick of Faber's graphite (4) was taken from one of the *Crayons d'artiste* by this maker. 3 and 5 were parallelopipedal carbon rods, the one being that used for a Bunsen element and the other a good carbon cut from a Munich retort. 3 was of so great resistance, that its use in a battery should be carefully avoided. 6 was a plate from a Bunsen plate-battery, intended to work a Ruhmkorff's induction apparatus. None of the carbons had been used, and all were measured when well dried. 7 was a stick from a Foucault's lamp furnished by Duboscq. The conductivity of both manganese ores is also very low; that of a concentrated solution of zinc-sulphate would be higher than the conductivity of the manganite.

Matthiessen has also given the conductivities of several kinds of carbons; these reduced to mercury = 1 are for—

Graphite (from pencil)	between 0·0425 and 0·0024
Battery carbon	0·00177
Gas carbon	0·02240

P. H.

Phenomena of Electric Oscillation. By L. Mouton.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1387.)

In a previous communication the Author has shown that, given an induction-coil the poles of which are insulated from one another, and separated by such a distance as to prevent

production of spark phenomena when the inducing circuit is broken, the difference of tension presented by the two poles passes through the following phases:—It is nil so long as the inducing circuit remains closed, but when this is broken a difference of potential appears, which increases, attains a maximum, returns to zero, changes sign, and so oscillates about the zero value, before definitely returning to this value. The exact evaluation of the periods of oscillation needs, on account of their short duration, an experimental arrangement that the Author had been unable to attain. Such an apparatus the Author has now procured, and with its aid has arrived at the following results. A difference of tension appears between the two extremities of the induced wire at the end of a time which is less than four-millionths of a second after metallic rupture of the inducing circuit. This difference of potential increases; its direction is such that if the two extremities of the induced wire were reconnected by a conductor it would give a direct induced current, and thus, doubtless, would be produced the whole or part of the induction spark if the two extremities were separated by only a thin layer of air or a column of rarefied gas. The difference of potential having attained a maximum, diminishes, returns to zero, and is reproduced in inverse direction, and thus oscillates about zero. The successive maxima diminish. It is probable that the number of oscillations is theoretically infinite; in the first experiments the twentieth maximum gave as much as one hundred and sixty divisions of the electrometer scale. The periods between the two zeros are rigorously equal, with exception of the first, which is always longer. These periods differ with the induction-coil used, but for a given bobbin they are independent of the number of convolutions composing the inducing coil, and of the intensity of the inducing current, at least within the limits of the Author's experiments. The duration of the first period, taking for unit of time the thousandth of a second, was for a coil of 13,860 convolutions between 0·108 and 0·112, or say 0·110. With a coil of 7,260 convolutions it was 0·035. The general duration of the isochronous periods following the first was between 0·076 and 0·077 for the larger coil, and between 0·023 and 0·025 for the smaller coil. If soft iron wires are introduced into the inducing bobbin their effect is to lengthen the first period only. Thus, pieces of iron wire 1 millimètre in diameter being introduced into the bobbin successively to the number of ten, twenty, and forty, the periods corresponding to the first period, with the large bobbin, instead of 0·110 were 0·144, 0·153, 0·171, and for the isochronous periods 0·076 as before. The duration of these isochronous oscillations appears therefore to depend on the bobbin itself. The Author finds that the ratio of the durations of the isochronous oscillations of the two coils is equal to the ratio of the lengths of the wires to their diameters. This ratio will represent a kind of resistance to the electric flow along the surfaces, and in which the perimeter replaces the section.

P. H.

Influence of Temperature on Magnetisation.

By J. M. Gaugain.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1422.)

The experiments detailed by the Author in a former communication[1] were performed on bars of different forms and dimensions, but of the same class of manufacture, that is, from Sheffield steel. These experiments have been repeated with other descriptions of steel with different results. When a bar of Sheffield steel is heated gradually, and in contact with the pole of a magnet, its total magnetisation increases with the temperature to a certain limit, then diminishes when this limit is passed. The temperature corresponding to maximum magnetisation has not been ascertained with exactness, but according to some thermo-electric determinations, the Author believes it to be above 130°.[2] When Allevard steel is substituted, the total magnetisation does not diminish even when the steel takes a blue tint at a temperature of 300°. These results are modified when the experiments are performed on bars that have been several times heated and cooled. The following tables give the induced currents due to demagnetisation of a Sheffield steel bar in contact with a magnet-pole under the conditions of temperature and temper described:—

	At 20°.	At 300°.
Before heating	24·1	—
After first heating	42·9	30·0
„ second „	43·0	31·0
„ third „	42·9	31·1
„ fourth „	42·5	30·9

With an Allevard steel bar:—

Before heating	22·0	—
After first heating	36·1	32·1
„ second „	37·0	32·8
„ third „	37·0	32·6

Both steels have nearly the same permanent modification when they undergo the same alternations of temperature, but the temporary modification is greater for the Sheffield than for the Allevard steel. P. H.

[1] Comptes rendus, 20th March, 1876. [2] Presumably centigrade.—P.H.

Automatic Discharger for Lightning-Conductors.

By J. SERRA-CARPI.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 41.)

This apparatus consists of a copper lever, with equal arms of about 11·8 inches in length, turning on a pivot in communication with the portion of the lightning-conductor which carries the discharge to earth. At one of the extremities of this lever is a gilded button, 2 inches from the end of the insulated conductor; the other extremity is terminated by a piece of soft iron. When the extremity of the insulated lever has acquired sufficient tension to produce small sparks, the attraction between the gilt globe and the end of the insulated conductor causes the lever to turn on its pivot and put itself into contact with the conductor. In order that this contact may be maintained in windy weather, a magnet is arranged to attract the piece of soft iron.

P. H.

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TO THE

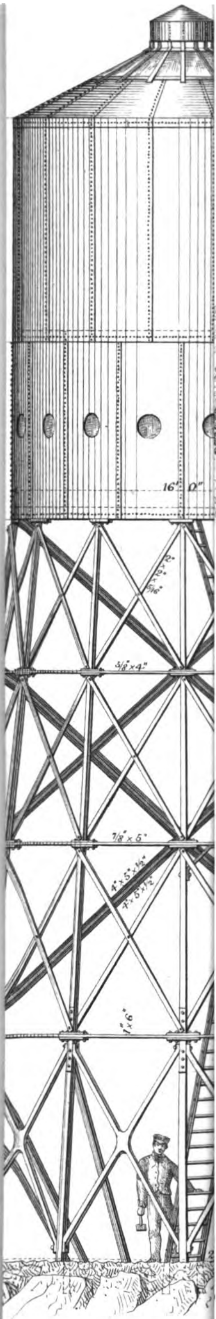
MINUTES OF PROCEEDINGS,

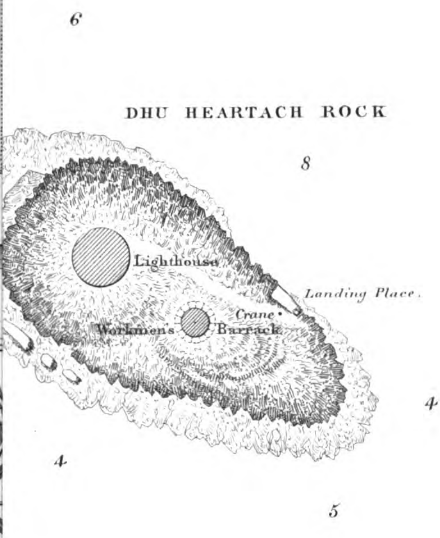
1875–76.—Part IV.

END OF VOL. XLVI.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET, AND CHARING CROSS.

OUSE. PLATE 1.





NOTE. *The Soundings are in* ***Fathoms,*** *at Low Water Spring Tides.*

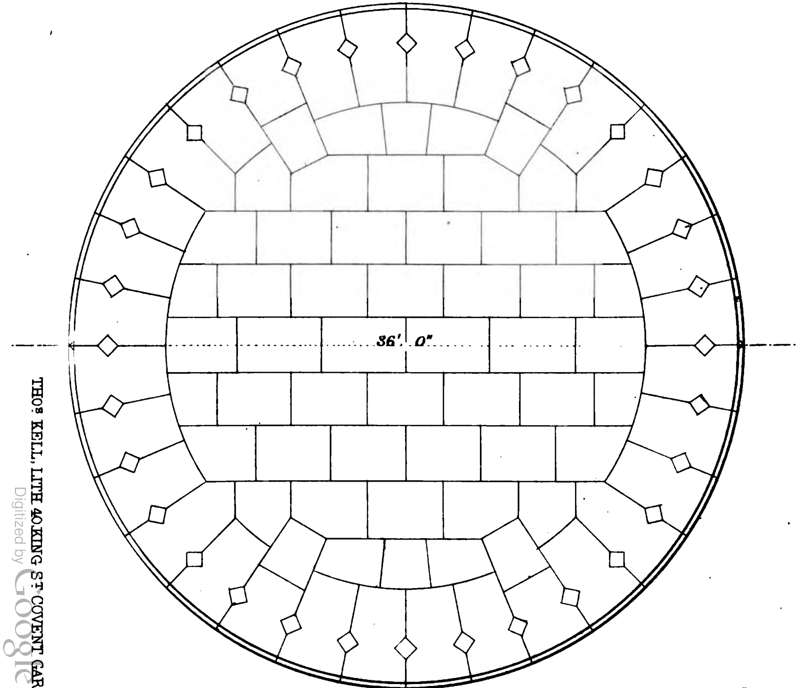
F LIGHTHOUSE, BARRACK &c.

WORKMEN'S BARRACK

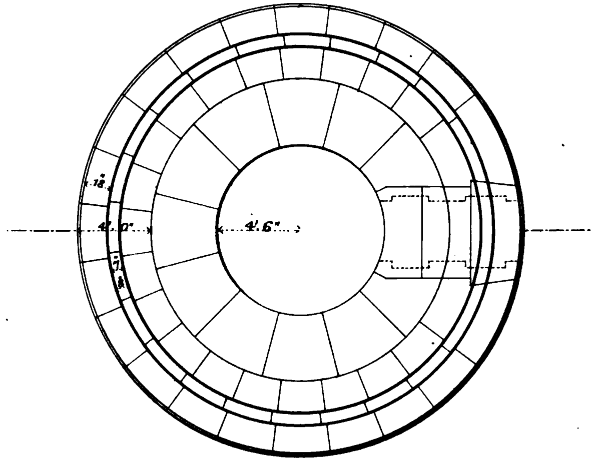
Scale 2 3 4 5 6 7 8 9 10 300 400 500 *Feet.*

THOS KELL, LITH 40, KING ST COVENT GARDEN

COURSE No. 26.



COURSE No. 1.



COURSE No. 27.

Scale of Feet.

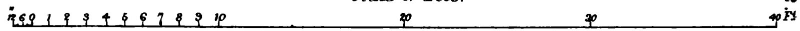
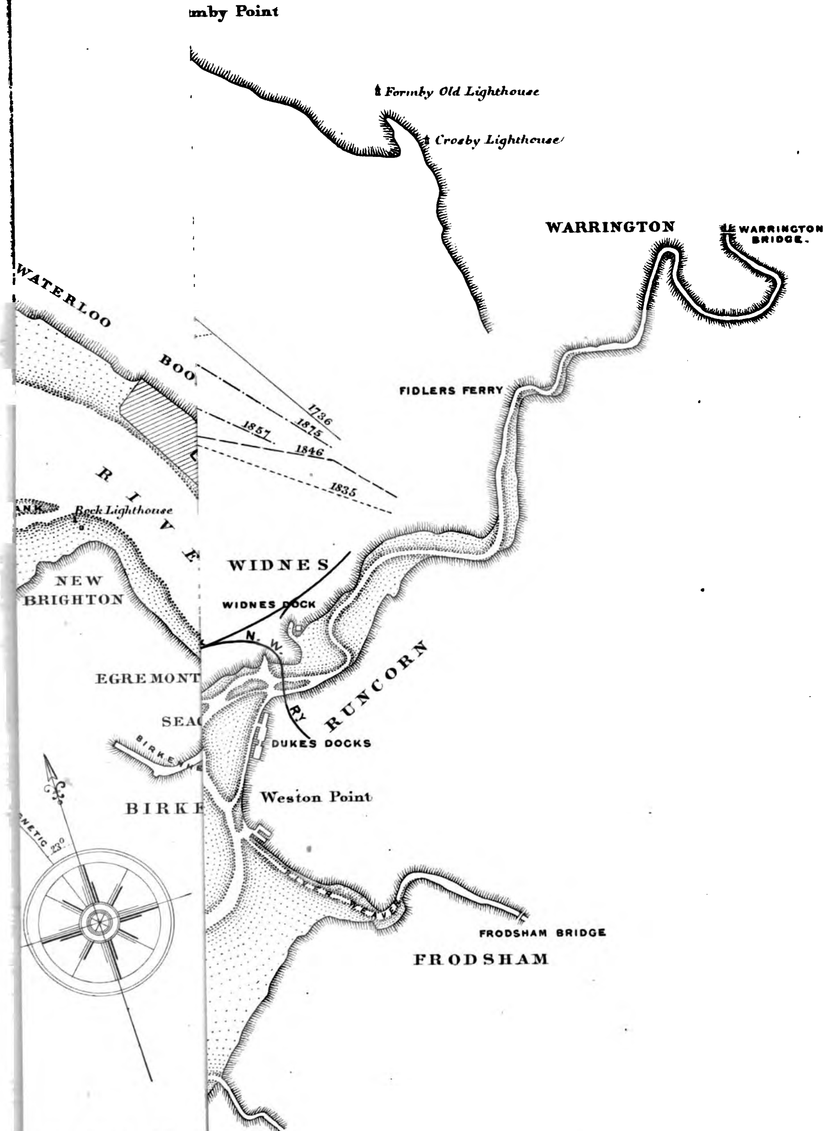


PLATE 2.

THOS KELL, LITH 40 KING ST COVENT GARDEN

TH



RAL PLAN OF RI

Low Water of

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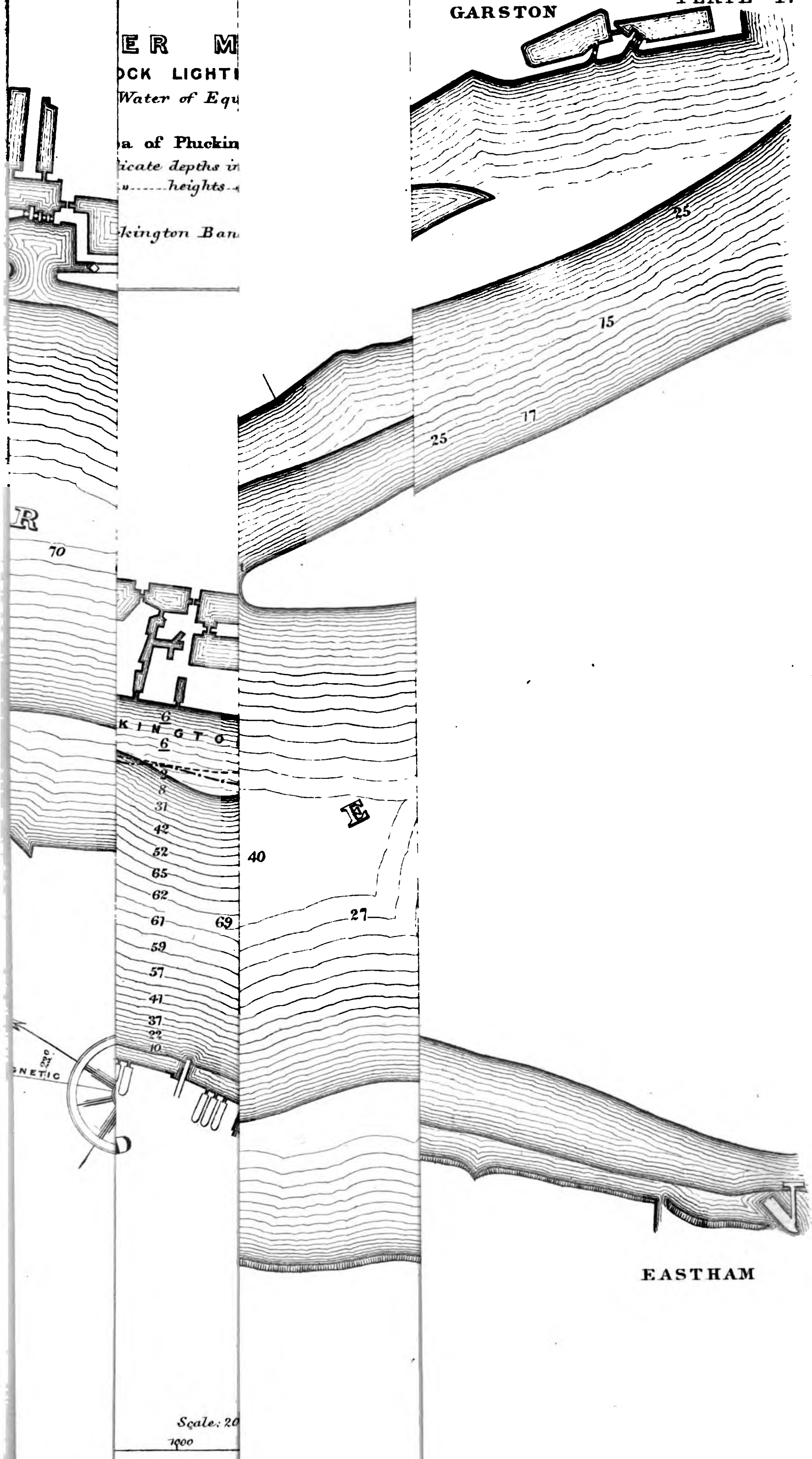
Minutes of Procee

THOS KELL, LITH 40, KING ST COVENT GARDEN

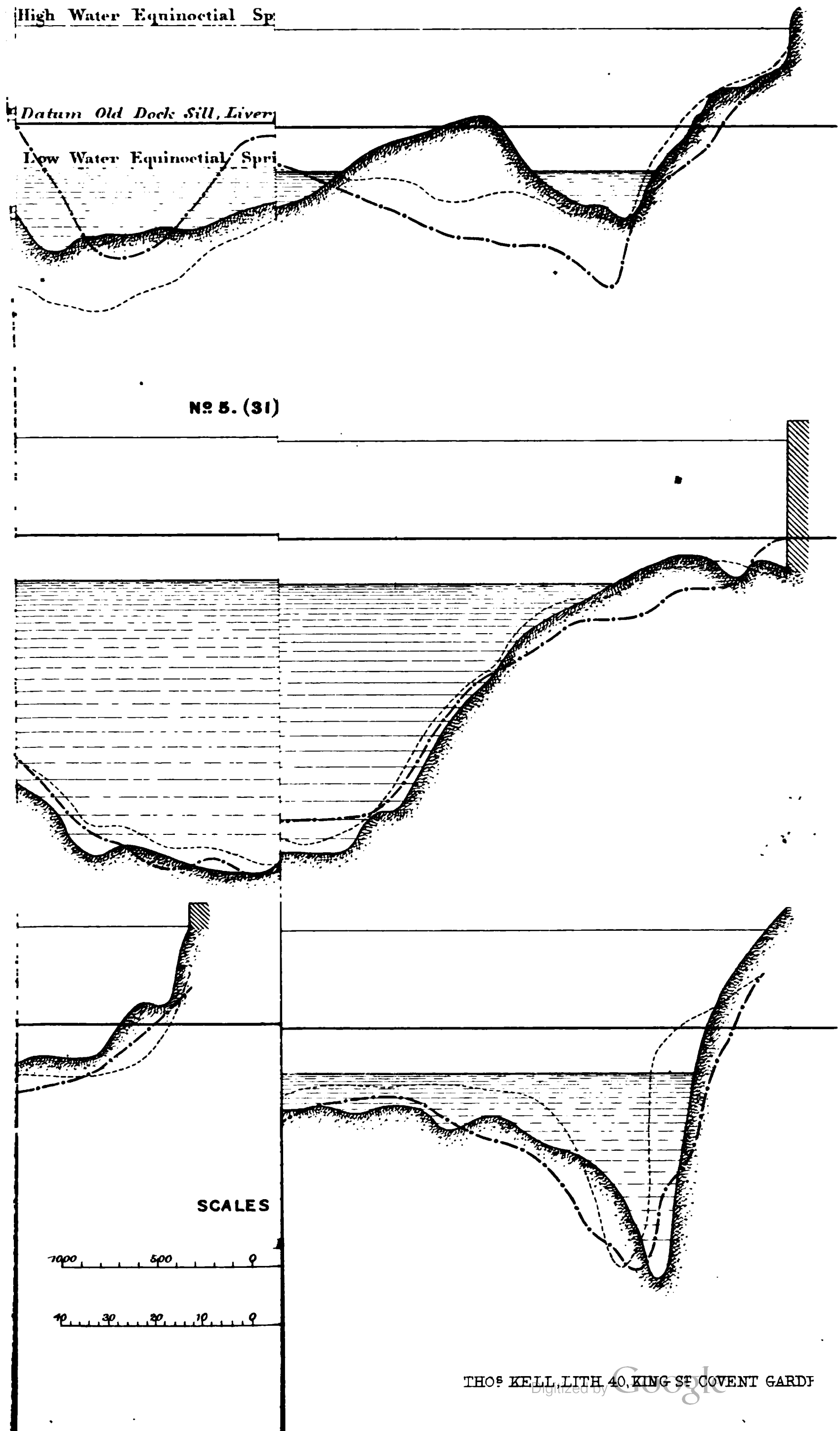
PLATE 4.



Institution c

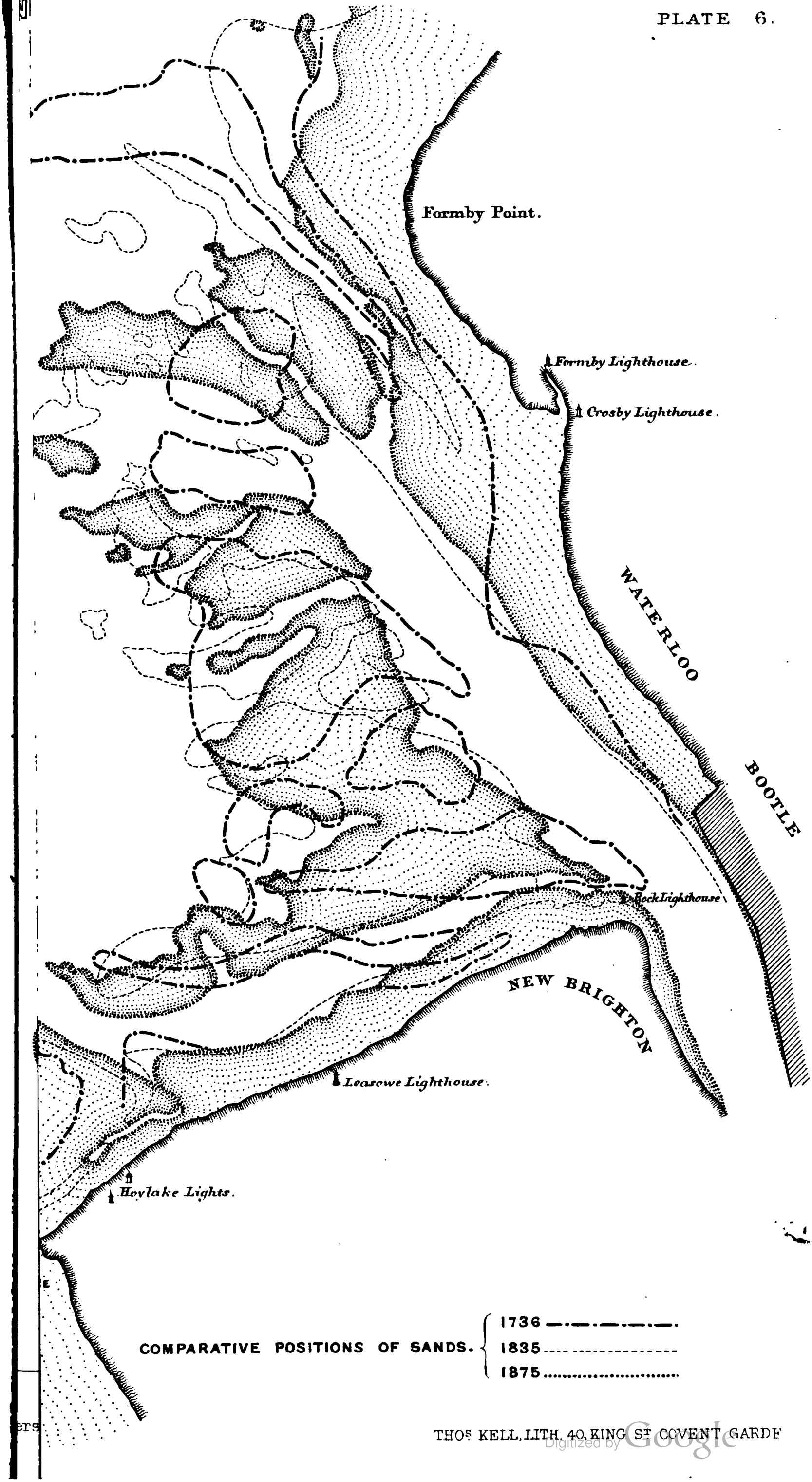
THOS KELL, LITH. 40, KING ST COVENT GARDEN

PLATE 5.



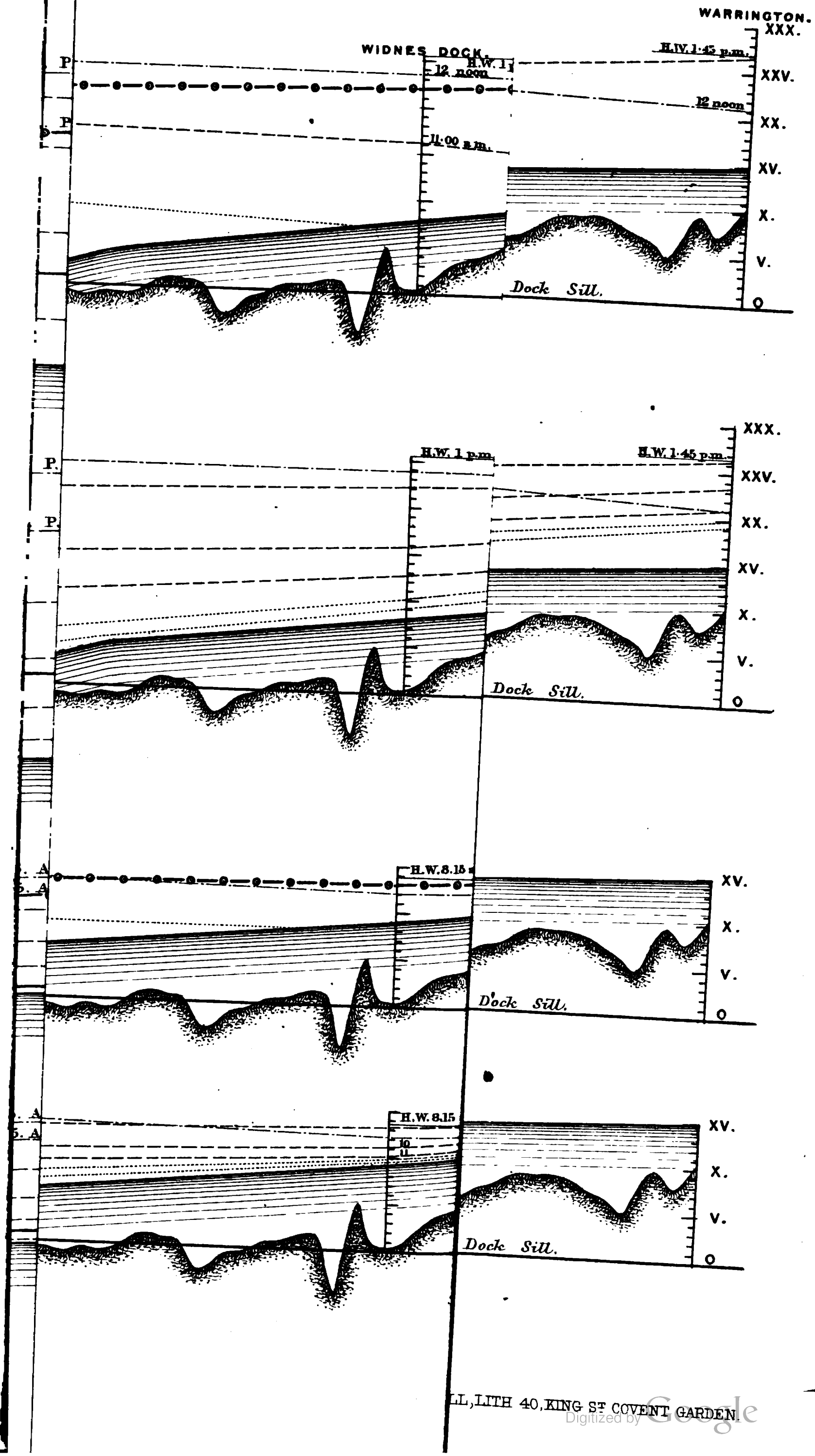
THOS KELL, LITH 40, KING ST COVENT GARDE

PLATE 6.

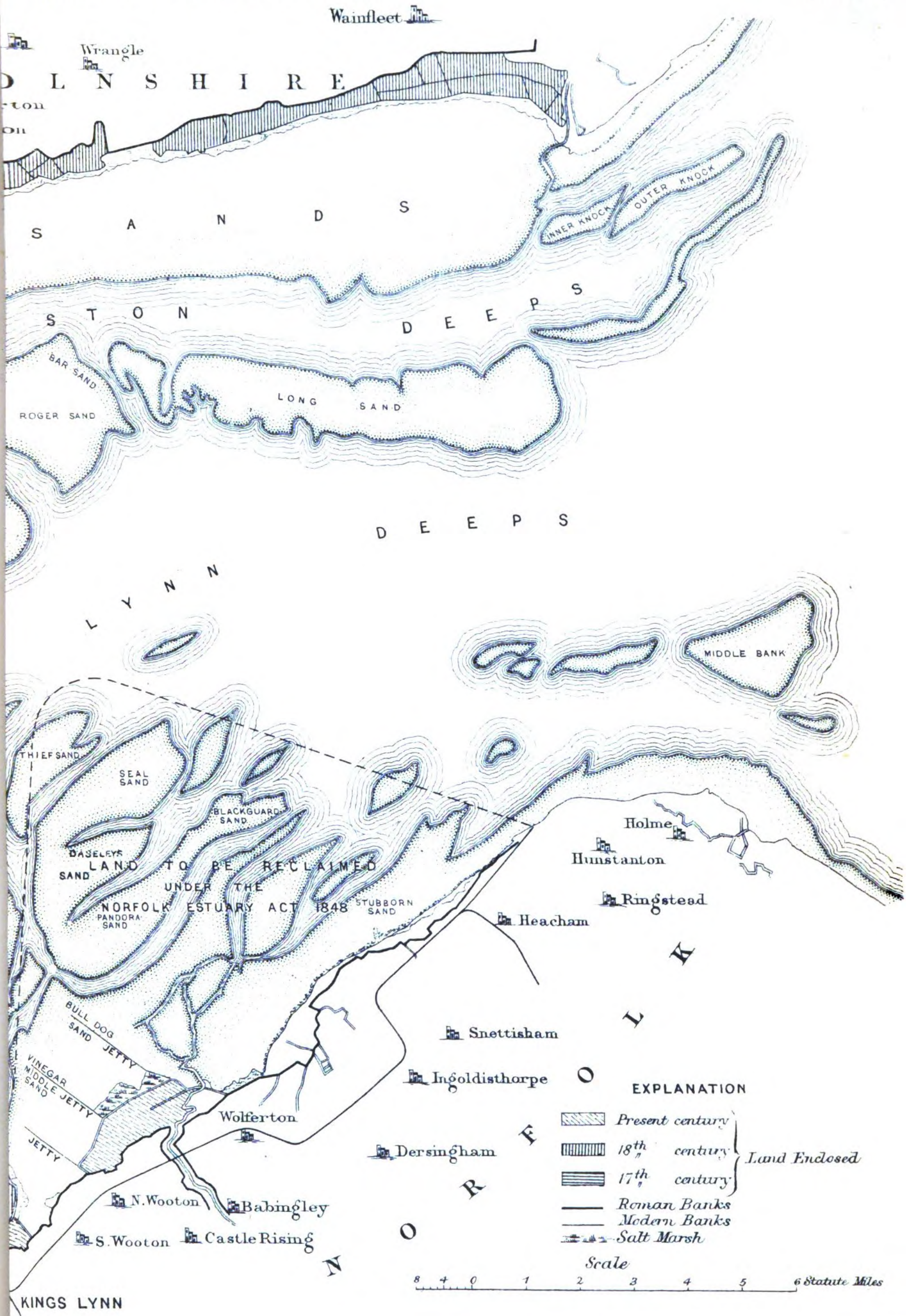


THOS KELL, LITH. 40, KING ST COVENT GARDE

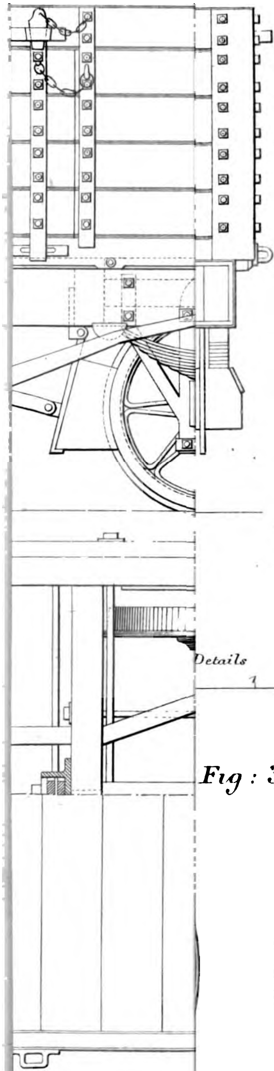
PLATE 7.



LL, LITH 40, KING S^T COVENT GARDEN.



THOS KELL, LITH. 40 KING ST COVENT



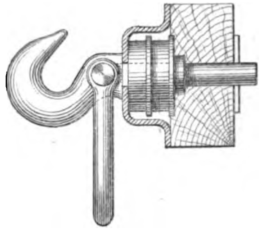
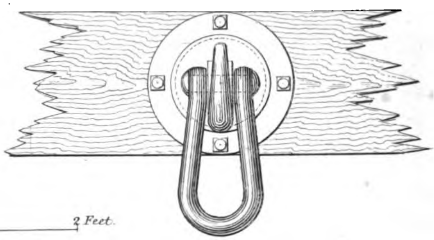


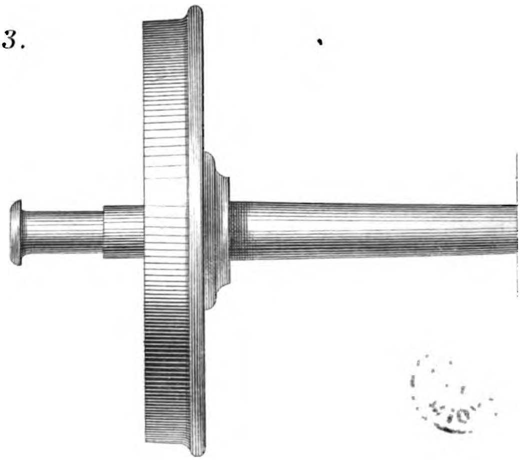
Fig : 4.



Details

1 2 *Feet.*

Fig : 3.

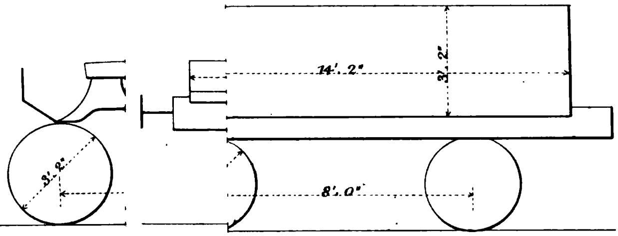


ng.

1 5 *Feet.*

THOS KELL, LITH. 40, KING ST COVENT GARDEN

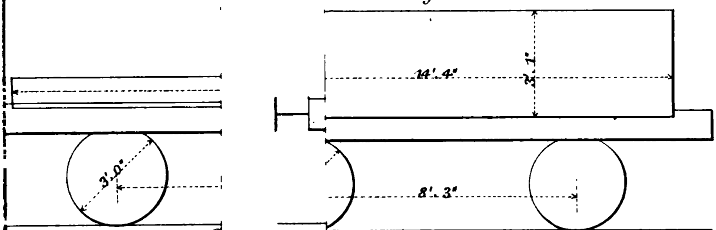
Fig: 14.



BROUGHAM B
Tare (

Gauge 4'. 8½".
WAGON Co. Standard Coal Wagon.
ty 8 Tons_ Tare 4 Tons 9 Cwt. 1qr.
Ton of Dead weight 1 Ton 16 Cwt. 3 qrs.

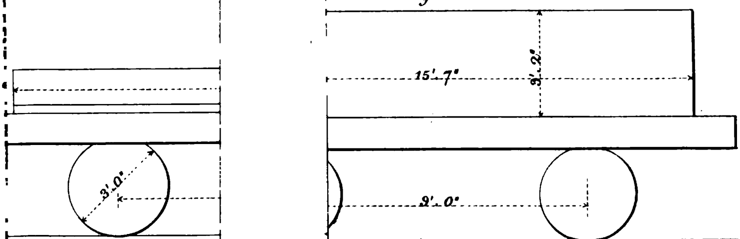
Fig: 15.



G
NDON & NORTH WESTER
Capacity 6 Tons
Capacity per Ton of

Gauge 4'. 8½".
WAGON Co. Standard Coal Wagon,
acity 8 Tons_ Tare 4 Tons 15 Cwt. _
r Ton of Dead weight 1 Ton 13 Cwt. 3 qrs.

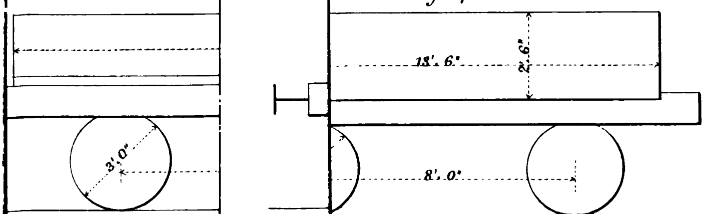
Fig: 16.



ONDON & NORTH WESTE
Capacity 7 Ton
Capacity per Ton o

Gauge 4'. 8½".
WAGON Co. Broughton Coal Co. Wagon.
city 10 Tons_ Tare 4 Tons 12 Cwt.
Ton of Dead weight 2 Tons 3 Cwt. 2 qrs.

Fig: 17.



LONDON & NORTH WES
Capacity 7 Tons
Capacity per Ton o

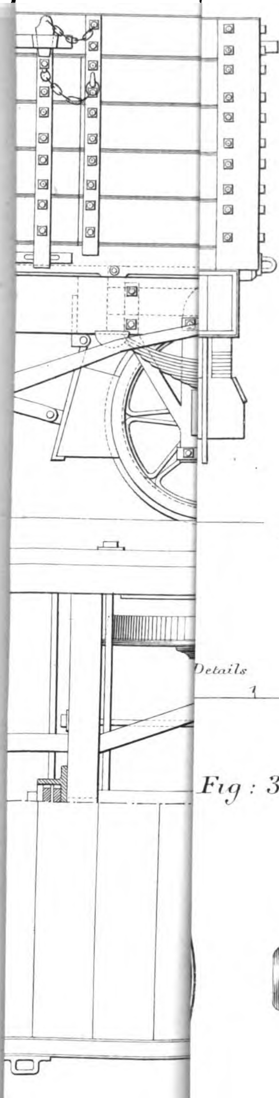
Gauge 4'. 8½".
OLITAN WAGON Co. Coal Wagon.
city 6 Tons_ Tare 4 Tons 1 Cwt.
Ton of Dead weight 1 Ton 9 Cwt. 3 qrs.

THOs. KELL, LITH. 40, KING St. COVENT GARDEN.

NKMENTS IN THE WASH.

PLATE 8.

THOS KELL, LITH. 40 KING ST. COVENT



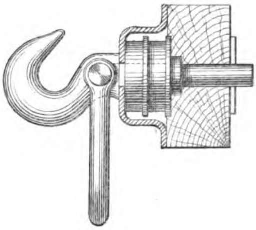
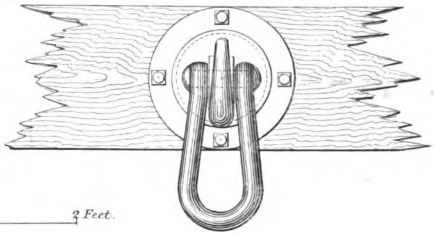


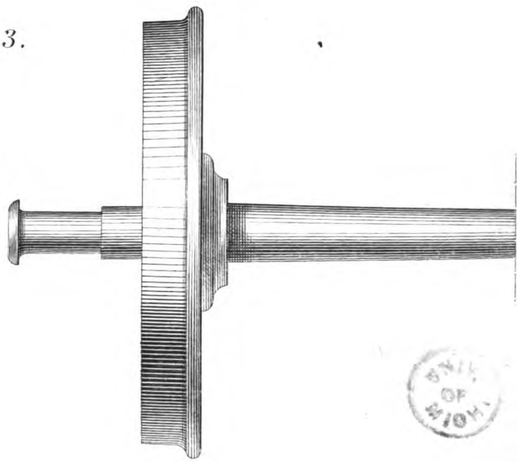
Fig: 4.



Details

1 2 Feet.

Fig: 3.

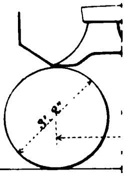


ng.

1 5 Feet

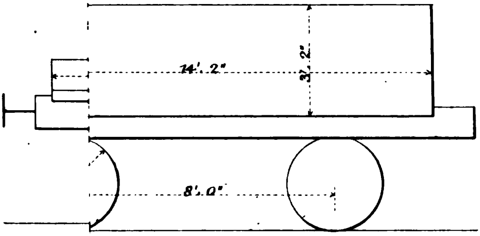
Minutes of Proceedi

THO^S KELL, LITH. 40, KING S^T COVENT GARDEN

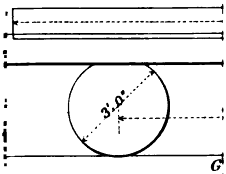


BROUGHAM B
Tare (

Fig: 14.

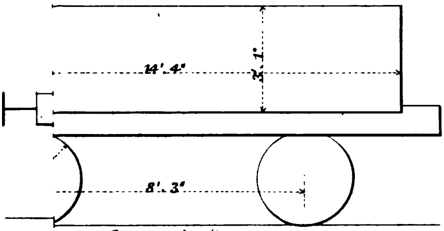


Gauge 4'. 8½".
WAGON Co. Standard Coal Wagon.
ty 8 Tons _ Tare 4 Tons 9 Cwt. 1 qr.
Ton of Dead weight 1 Ton 15 Cwt. 3 qrs.

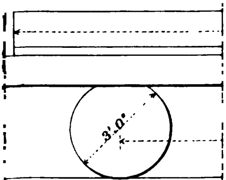


G
NDON & NORTH WESTER
Capacity 6 Tons
Capacity per Ton of

Fig: 15.

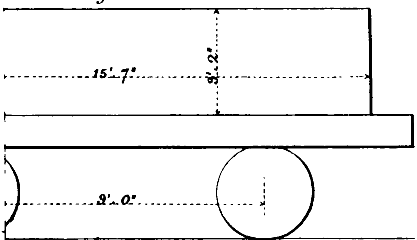


Gauge 4'. 8½".
WAGON Co. Standard Coal Wagon,
city 8 Tons _ Tare 4 Tons 15 Cwt. _
r Ton of Dead weight 1 Ton 13 Cwt. 3 qrs.

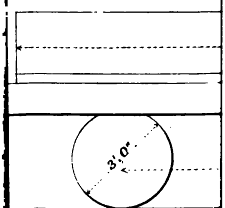


NDON & NORTH WESTE
Capacity 7 Ton
Capacity per Ton o

Fig: 16.

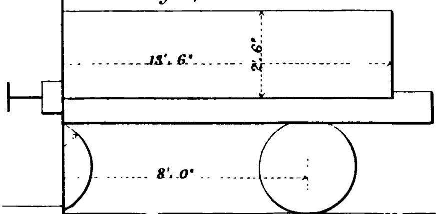


Gauge 4'. 8½".
WAGON Co. Broughton Coal Co. Wagon.
city 10 Tons _ Tare 4 Tons 12 Cwt.
Ton of Dead weight 2 Tons 3 Cwt. 2 qrs.



LONDON & NORTH WES
Capacity 7 Tons
Capacity per Ton o

Fig: 17.



Gauge 4'. 8½".
OLITAN WAGON Co. Coal Wagon.
city 6 Tons _ Tare 4 Tons 1 Cwt.
Ton of Dead weight 1 Ton 9 Cwt. 3 qrs.

THOS. KELL, LITH. 40 KING ST. COVENT GARDEN.

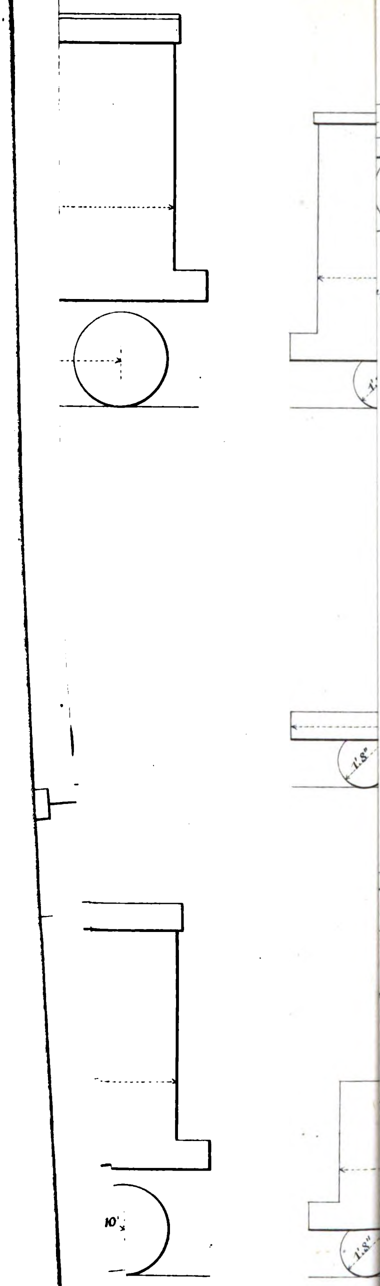
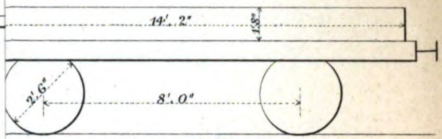


Fig: 32.



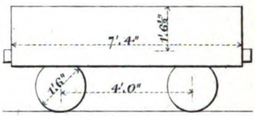
Gauge 3'. 6".

SOUDAN RY. Hinged Side Wagon.

Capacity 6 Tons.— Tare 3 Tons 8 Cwt. 2 qrs.

pacity per Ton of Dead weight, 1 Ton 15 Cwt.

Fig: 33.



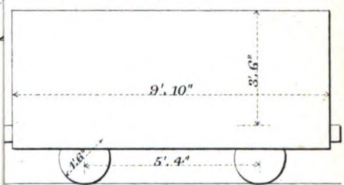
Gauge 2'.0".

FESTINIOG RY. Slate Wagon

Capacity 4 Tons.— Tare 1 Ton.

Capacity per Ton of Dead weight 4 Tons.

Fig: 34.



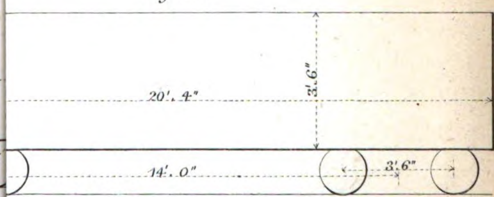
Gauge 2'.0".

FESTINIOG RY. Coal Wagon.

Capacity 5 Tons.— Tare 1 Ton 6 Cwt. 2 qrs.

pacity per Ton of Dead weight 3 Tons 15 Cwt. 2 qrs.

Fig: 35.



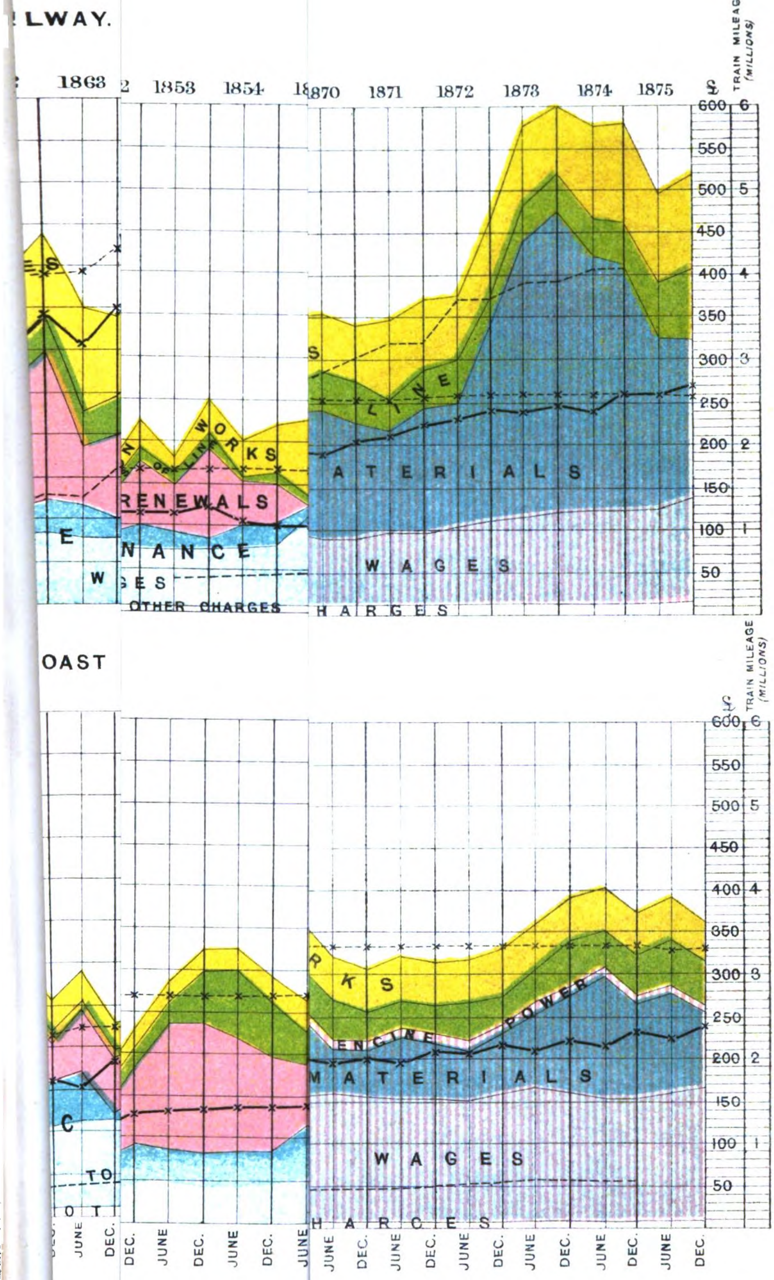
Gauge 2'.0".

FESTINIOG RY. Bogie Coal Wagon.

Capacity 12 Tons.— Tare 3 Tons 7 Cwt.

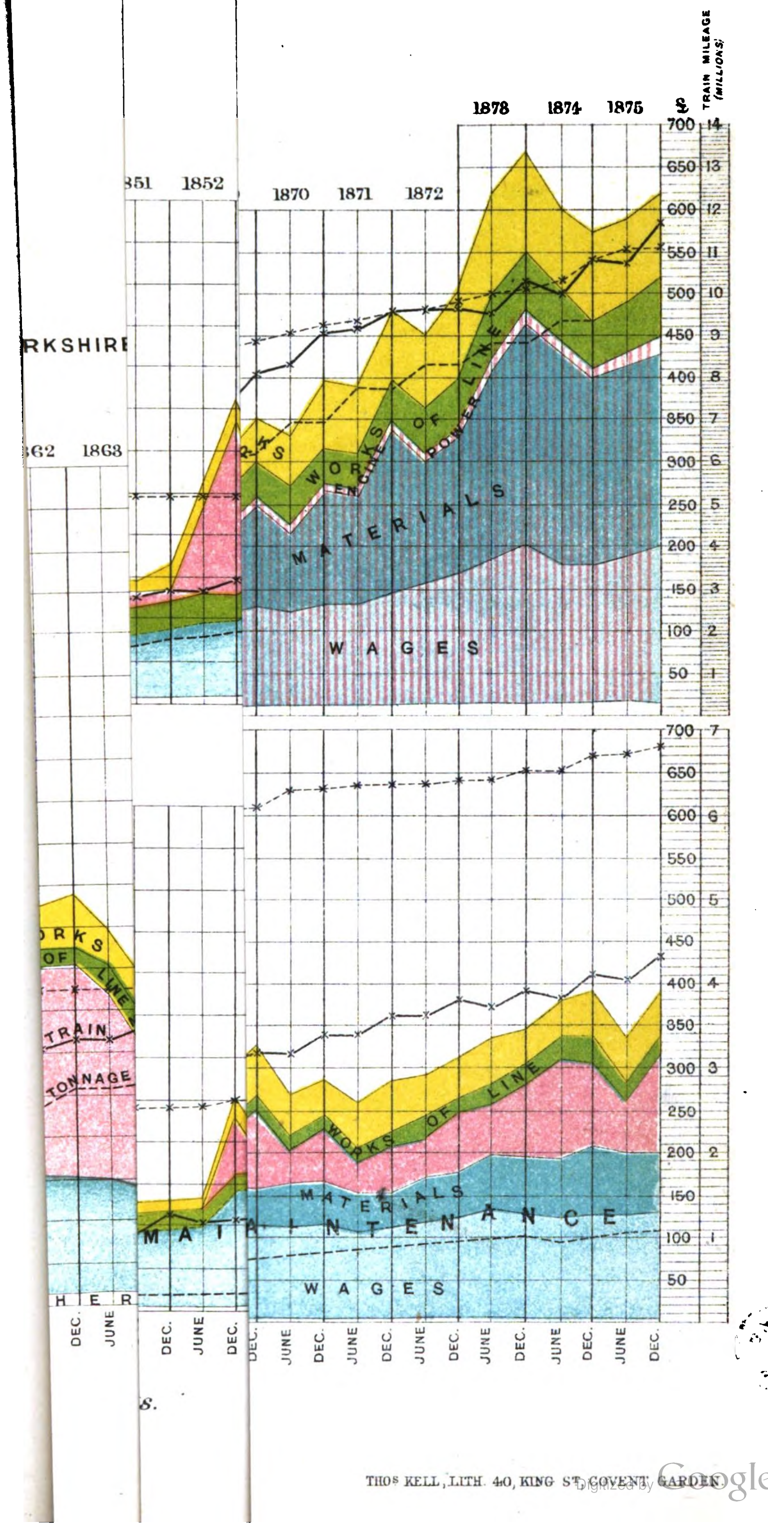
pacity per Ton of Dead weight 3 Tons 11 Cwt. 2 qrs.

THOS. KELL, LITH. 40 KING ST. COVENT GAR



THOS KELL, LITH. 40, KING ST. COVENT GARDEN.

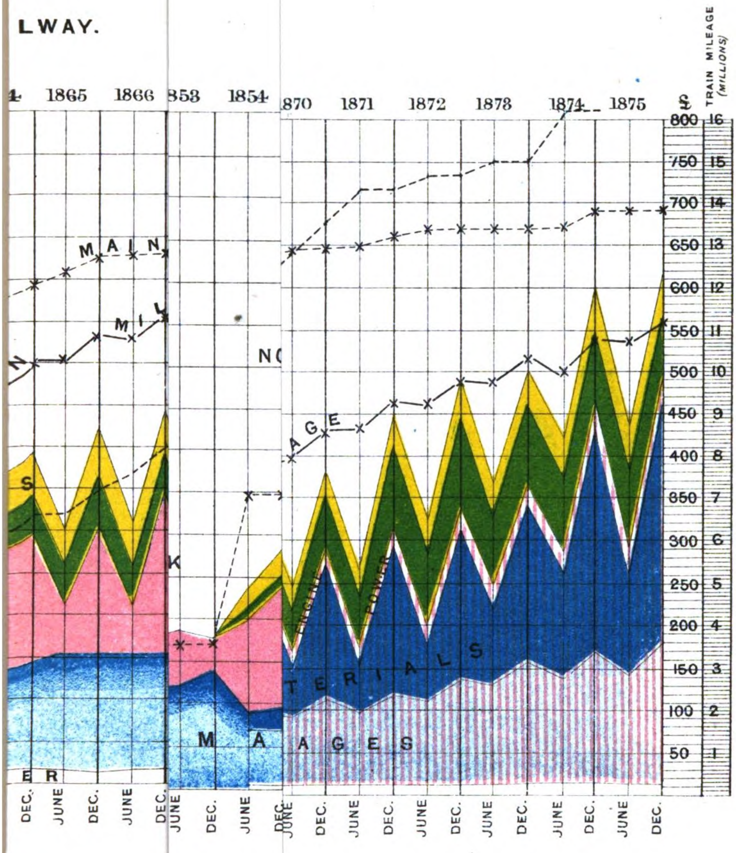
PLATE 13.



S.

THOS KELL, LITH. 40, KING ST COVENT GARDEN.

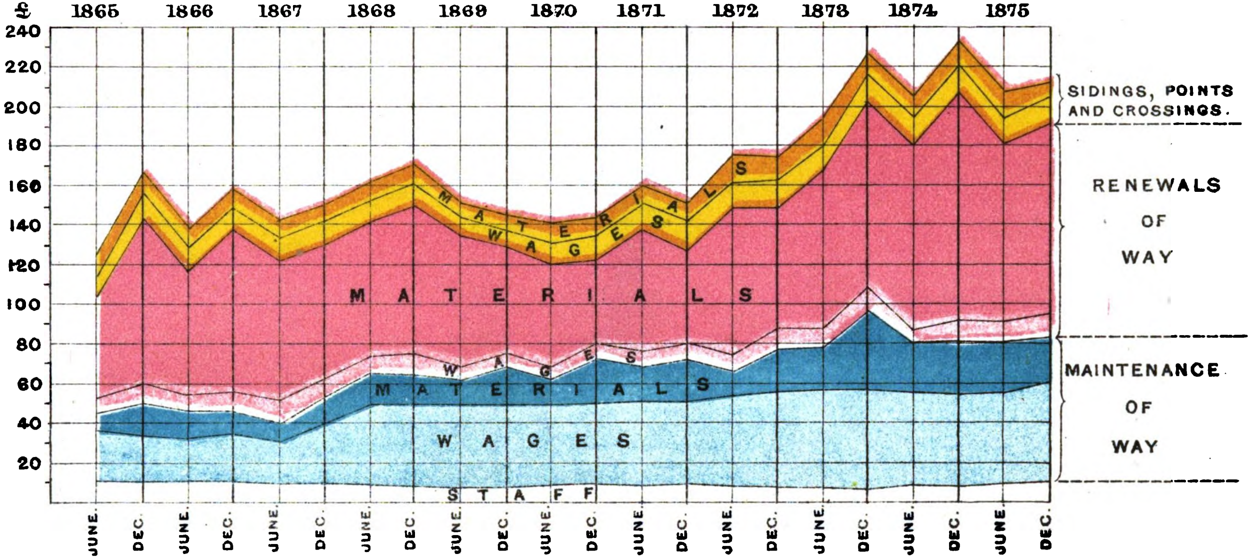
PLATE 14.



THOS KELL, LITH 40, KING ST, COVENT GARDEN.

GREAT NORTHERN RAILWAY.

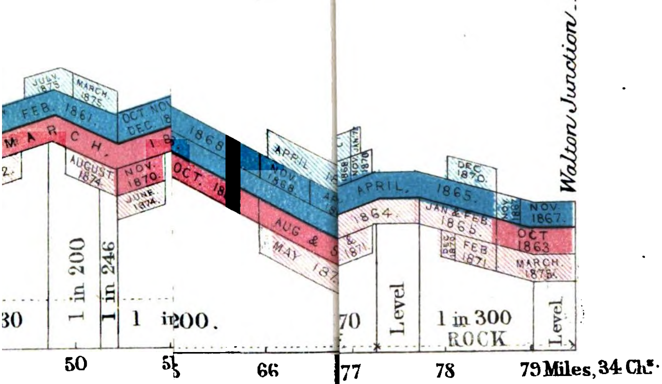
COST PER MILE PER ANNUM OF STAFF, MAINTENACE OF WAY, RENEWALS OF WAY & SIDINGS, POINTS, & CROSSINGS FROM JUNE 1865 TO DEC: 1875 (INCLUSIVE)



R. PRICE WILLIAMS, DELT

THOS KELL, LITH. 40, KING ST COVT GARDEN.

PLATE 16.



July, 1852. opened for Opened August, 1848.

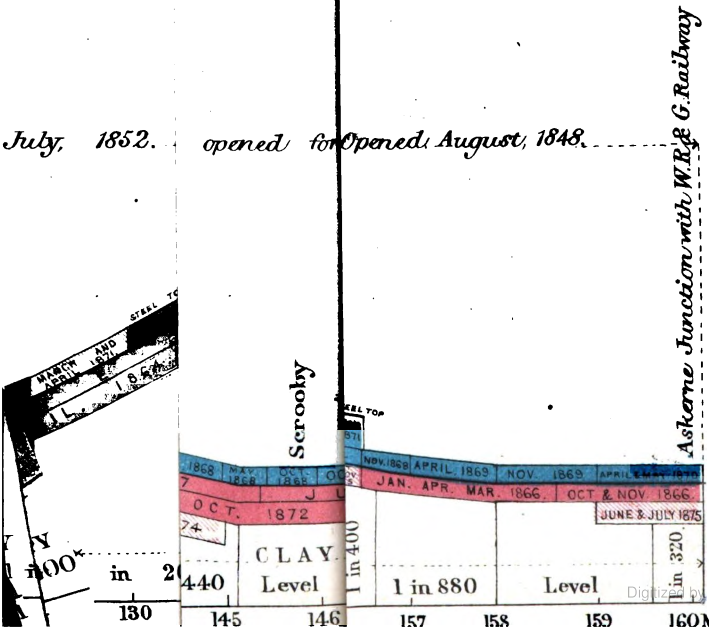
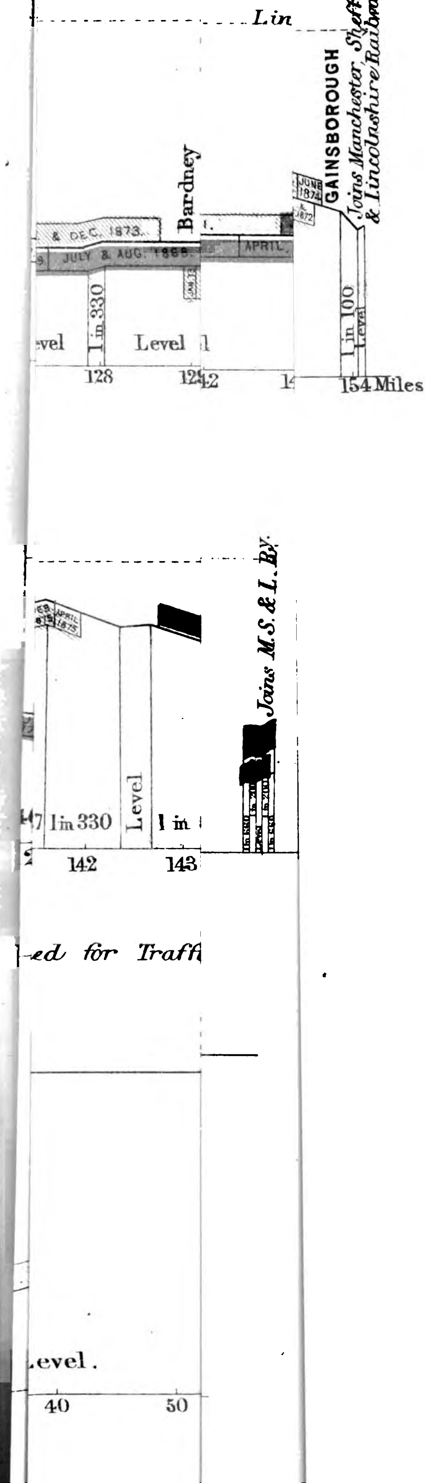


PLATE 17.


Lin
GAINSBOROUGH
Joins Manchester, Sheffield & Lincolnshire Railway.
Bardney
& DEC. 1873.
JULY & AUG. 1868.
APRIL.
JUNE 1874
1872
1 in 330
Level
1 in 100
Level
128
154 Miles
Joins M.S. & L. Ry.
APRIL 1875
1 in 330
Level
1 in
142
143
ed for Traffi
Level.
40
50

... Nº 5.)

D

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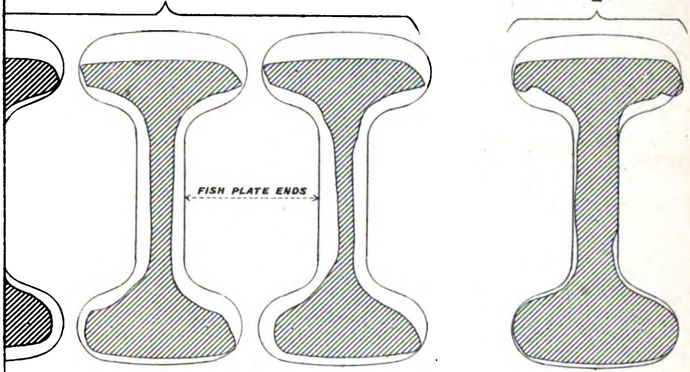
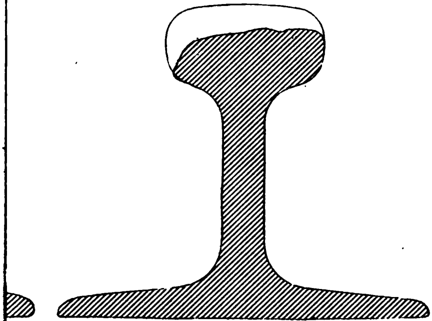
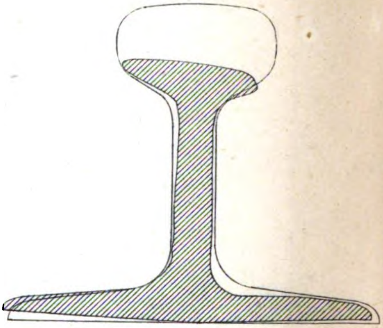


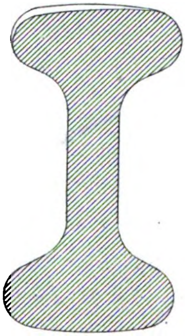
Nº 6.



Nº 6A.



TAFF VALE RAILWAY. *(Section referred to in Table Nº 11.)*



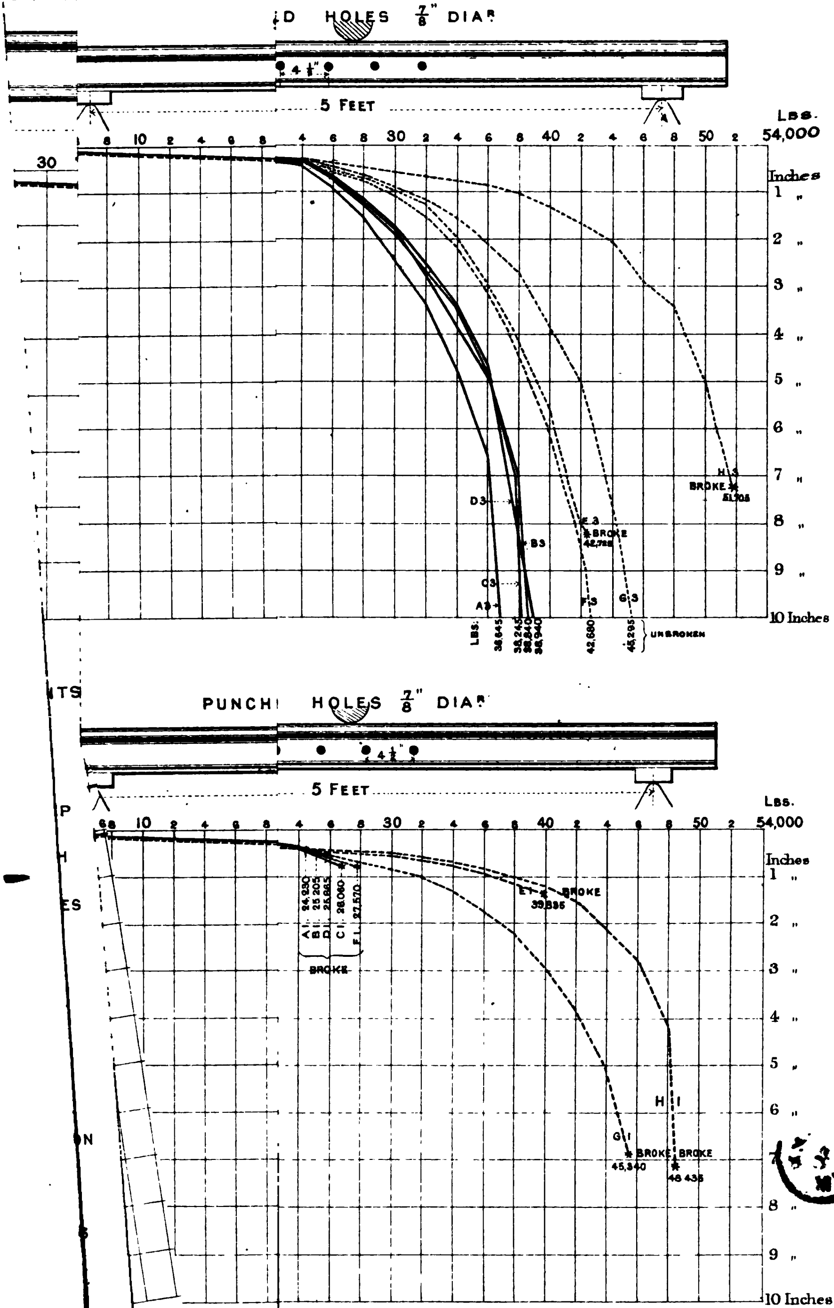
THOS KELL, LITH. 40, KING ST COVENT G

PLATE I

SHEWI

STRESS

DEFLEFORM STRESS. *(Mr Kirkaldy's Reports C & D.)*



Note:

875_7

THOS KELL LITH. 40 KING ST COVENT GARDEN.

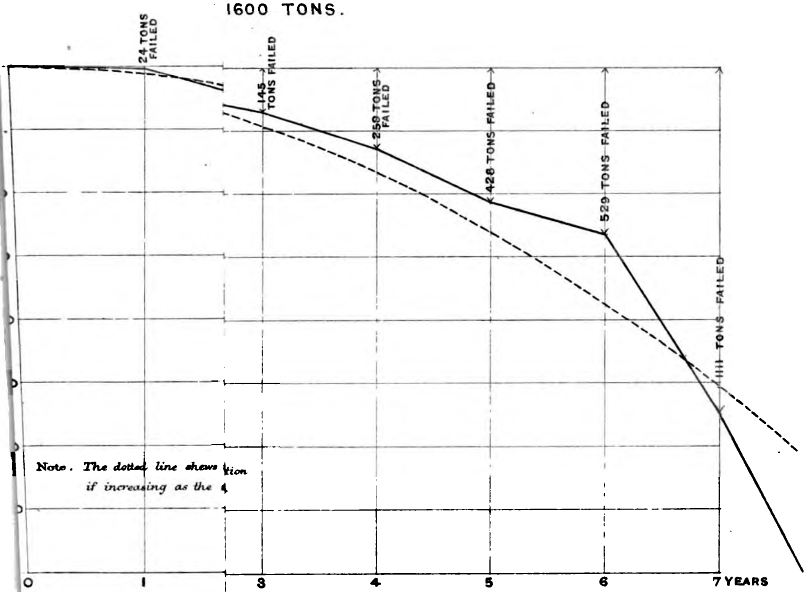
ILWAYS.

PLATE 20.

N THE GREAT NORTHERN RAILWAY.

F MAY 22ND 1865_ GUARANTEED 7 YEARS

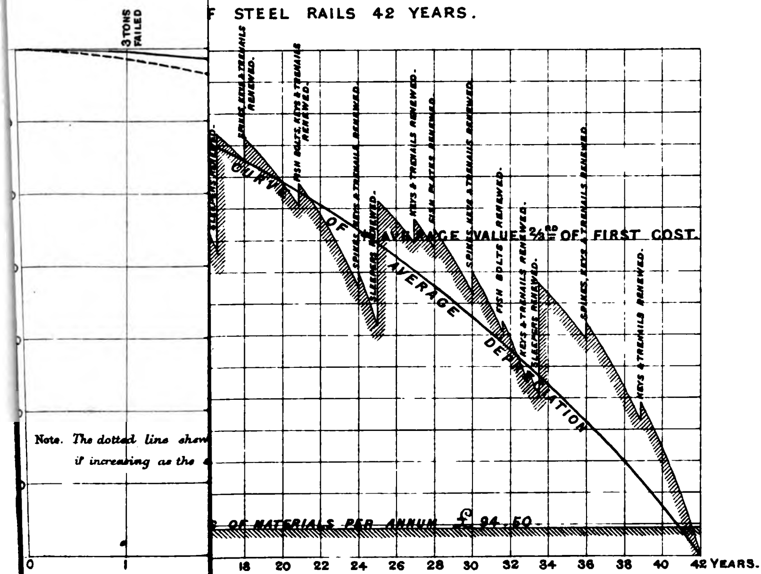
1600 TONS.



CO RATE OF DEPRECIATION OF A MILE OF PERMANENT WAY.

OF SLEEPERS 8 YEARS.

F STEEL RAILS 42 YEARS.



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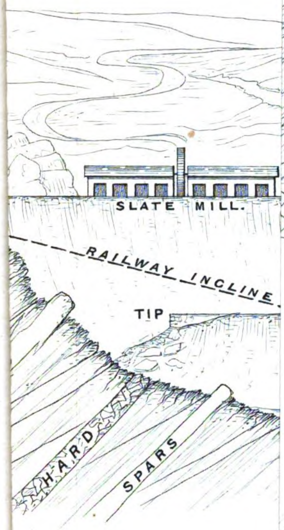
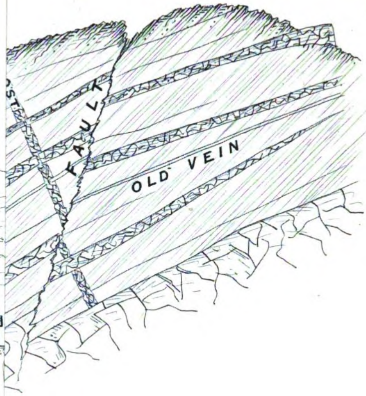
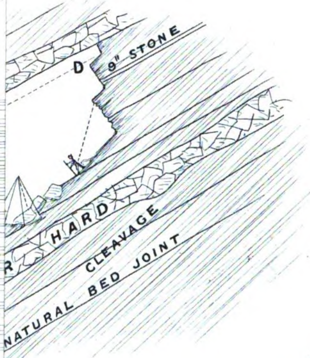
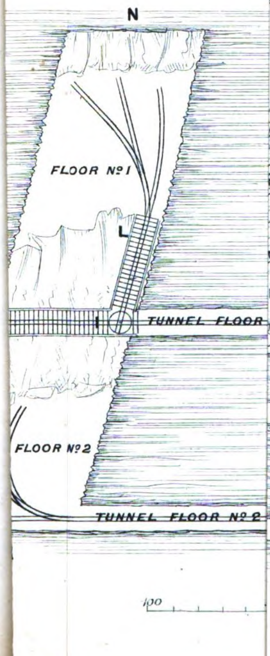
THOS KELL, LITH, 40. KING ST COVENT GARDEN.

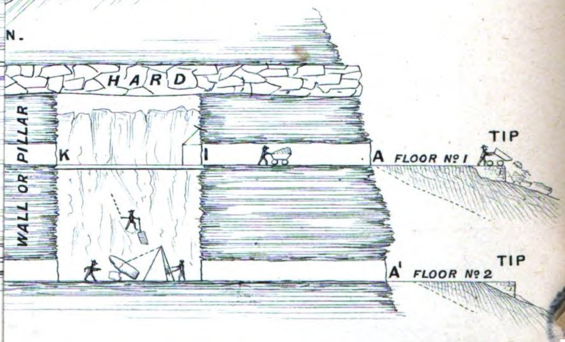






SOUTH





THOS KELL, LITH 40 KING ST COVENT GARDEN